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2/25/93

ENCLOSURES:

1. Entry forms: 3, Entries **A, B, C.**

2. Slides:

   Entry **(A)** 4 slides **Ezekial Series, #LNZ3.**
   Entry **(B)** 4 slides **Ezekial Series, #LNZ4.**
   Entry **(C)** 6 slides **Frontispiece #AQ2,** Boole's *Derivation...*

3. Brief Resume and Full Resume.

4. Photograph of Roman Verostko attending to a plotted brush stroke.

5. Slide documentation and artist's explanation.

6. Copy of the *Leonardo* article: "Epigenetic Painting: Software as Genotype".

7. Paperback Edition of *Derivation of the Laws* by George Boole. Note: On request we can send an insured copy of the limited edition for review. The limited edition is handbound in leather with original frontpiece and endpiece plots in 12 colors; zinc plates in 4 colors; hot cast type; handpulled on letterpress on Frankfurt text. Several original copies of the limited edition are available for exhibition.

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ARTIST'S ARTICLE

Epigenetic Painting: Software As Genotype

Roman Verostko

ABSTRACT

The author discusses a personal expert computer system driven by his own 'software art'. The software (with appropriate hardware) generates paintings and drawings that resemble the mature work of the artist's pre-electronic period, containing brush strokes that exhibit spontaneous qualities. The author outlines the prerequisite understanding necessary for writing the code, aspects of the software and hardware implementation, the biological analogue (epigenesis) and salient questions raised by the new procedure.

This paper explores issues related to software developed for personal use in my studio. The software, called Hodos, can generate paintings that bear an uncanny resemblance to my work made by hand over 20 years ago.

First, I will outline the features of the art concept that occupied the mature phases of this work long before I had any involvement with electronics. Then I shall focus on the essential features of the artistic decision procedures used in expressing the concept.

Next I shall review some of the salient features of the software that embodies these art form ideas. A review of several works generated by the software will show that they reflect essential characteristics of the earlier paintings.

Finally I shall demonstrate that this view offers two considerations for the future of art:

First, this kind of software is a medium of a different order from any previous medium. Because such software embodies the procedures for artistic improvisation, it can be used for innovative variation on the artist's theme without the artist being present. Although each work is one of a kind, it does belong to a family. We may ask, then, whether, to what extent, and how the artist's hand is present in the work or in a family of works. What can we say of the apparent feeling in the brush strokes?

Second, perhaps a more important consideration, is the 'quantum leap' in procedure or process. This new artistic process, while hardly the same, is remarkably analogous to the biological process of epigenesis. The software, Hodos, may be viewed as a genotype, because it is the code for how to make the work. The software can make a family of works, each work being unique (one of a kind, yet familial). The potential for crossing families of different artists opens the possibility of the hybridization of form and eventually of a genealogy of form.

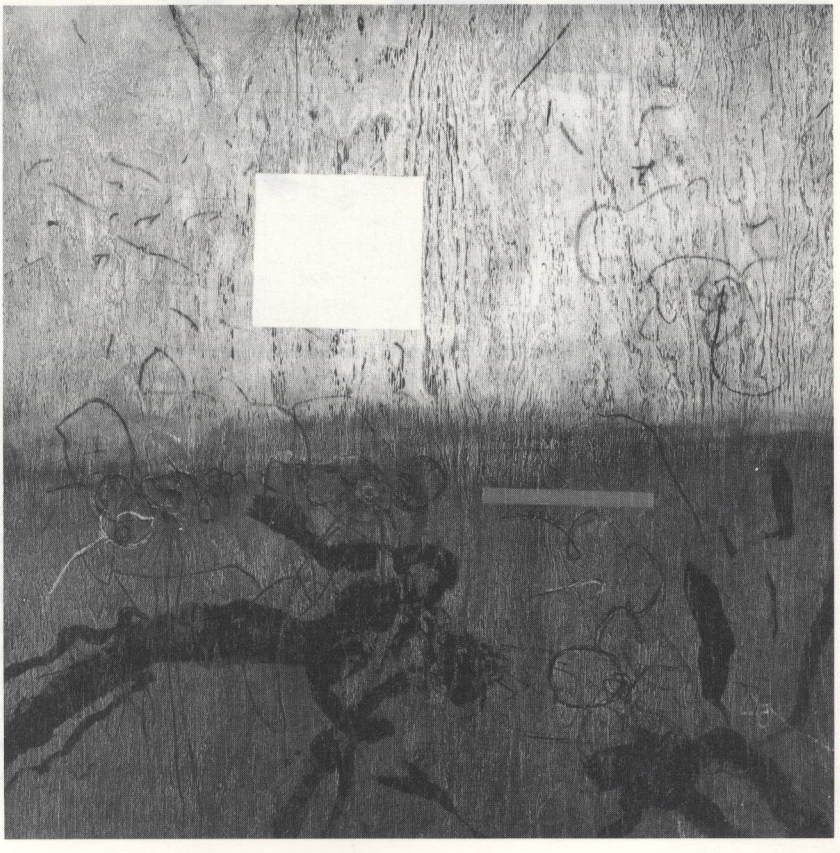


Fig. 1. *New City Series*, **acrylic, crayon and gesso on wood, 3 × 3 ft, 1966–1967. These works, executed by the artist's own hand, show his interest in the placement of control and uncontrol in the same visual field.**

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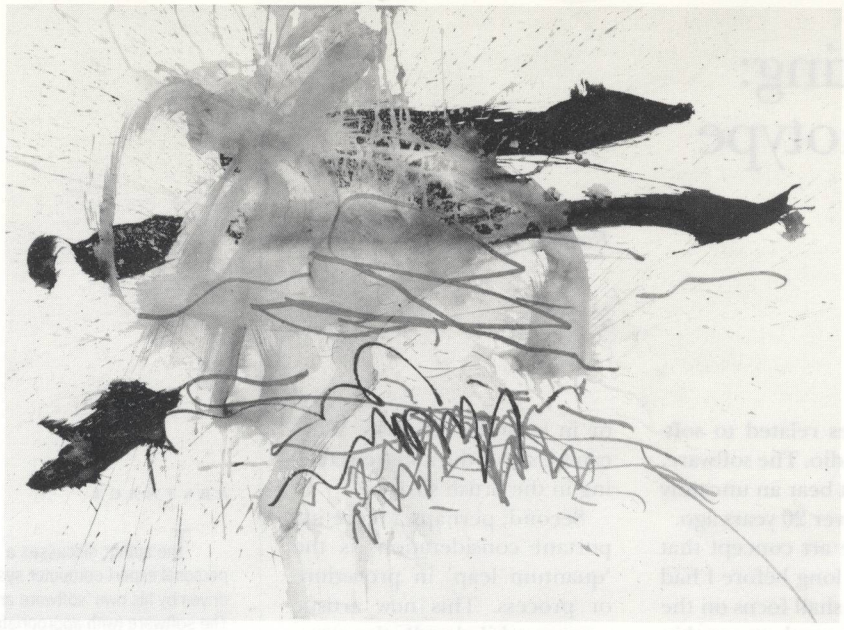


Fig. 2. Untitled, pencil, crayon and wash with India ink, 22 × 30 in, 1965. During the early 1960s the author made literally hundreds of such studies exploring human gestures and marking.

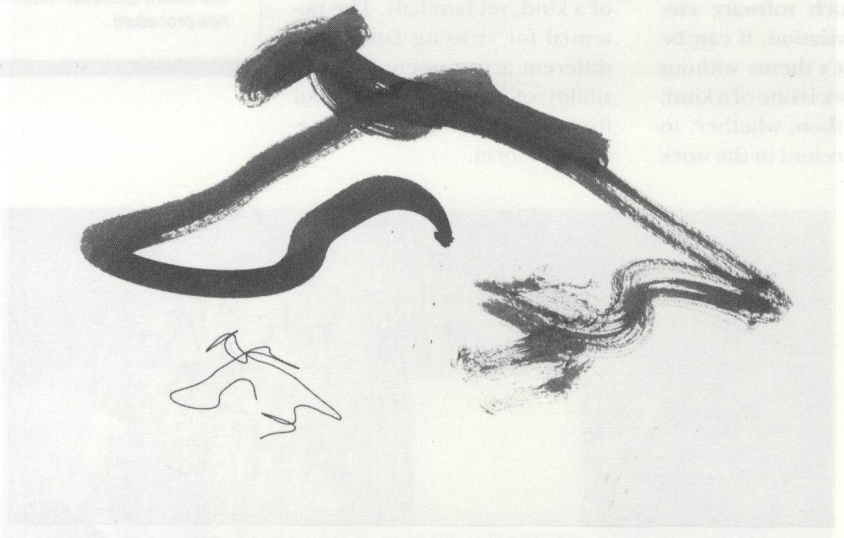


Fig. 3. A full-size brush stroke made with Hodos. The line configuration at the lower left of the brush stroke is a scaled pen stroke based on the same sequence that generated the brush stroke.

These considerations open the door to a series of interesting questions.

Preliminary Definitions

Before embarking on this discussion let us establish a few definitions that will apply in this paper. By *art concept* I mean an artist's ideas about how to make a work of art during a mature stylistic phase of development. By *software art* I mean software written or modified by an artist to carry out an art concept. Software art, as defined here, embodies the essential form-making capabilities of the artist, somewhat as a musical score embodies the musical ideas of a composer. By *personal expert system* I mean the software art and the hardware capable of processing the unique art concepts of a particular artist—in this case, a personal computer, a plotter, and the artist's software.

Theory and Practice: A Software Foundation

For over 20 years my paintings played with a visual dialectic between control and uncontrol. The paintings presented visual opposites in a kind of dialectic between order and chaos. The first works with this dialectic were executed between 1964 and 1968 on wooden panels with heavy grained wood (Fig. 1).

The Dance Between Order and Chaos

In the first phase of making these works, I carefully delineated several rectangular fields with variable spacing, creating visual movement relative to the overall field. These rectangles were carefully filled with a heavy synthetic impasto making a slightly raised rectangular relief on the panel.

Next, in very intense sessions, I would mark the remaining surface with spontaneous gestures, sometimes with brushes, sometimes with crayons or pencils. The gestural marks were imbedded in layers of colored stains that drew out the grain of the wood.

The gestural aspects of the work represented that aspect of human experience that might come from uncontrol, such as a feeling or an impulse. The dominant rule was that the marks had to be entirely spontaneous and without any conscious editing. For several years I had worked through hundreds of gestural works in an effort to elicit *irrational* marks (Fig. 2).

Through this process, in a kind of spiritual quest, one has to empty the self of thinking, be entirely present to the moment, and strive to be one with one's world. To be one with the brush, the crayon, the panel, the universe, in a free flowing gesture, was indeed the goal. Being most free was also being most joined. A gesture free of rigid aesthetic conceptions harmonizes easily with natural forces. This can be seen in the splash of paint that yields to unseen forces like gravity. It reveals the forces to which it yields and to which it is joined. Can this be achieved with software?

In the final stages of the work, the rectangular areas were painted according to another set of rules—but never absolutely so. Each rectangle was painted with a value and a color that gave it a visual 'push' or 'pull', making it appear slightly forward or slightly receding from the picture plane (see Fig. 1). Simultaneously, the placement

was intended to lend precarious but effective balance between all the lateral inclinations. The push or pull, advancing or receding, and the lateral movements were visual means of keeping a tension (opposition) between the rectangles while maintaining an equilibrium in the overall painting.

This approach was influenced by Piet Mondrian's concept of dynamic equilibrium. In reference to his own work before World War I, he wrote of how he perceived nature in his quest for unity:

> Impressed by the vastness of nature, I was trying to express its expansion, rest, and unity. . . . To create unity, art has to follow not nature's aspect but what nature really is. Appearing in oppositions, nature is unity [1].

Mondrian's perception that one must follow what nature really is and not nature's 'aspect' suggests that he perceived a deeper unity than lay in surface appearances. His search for that deeper force led him to see that life springs from the tension of opposites and that he could make art that reflected this dynamic. For him this dynamic had a profound spiritual meaning that he could manifest in works that obtained a dynamic equilibrium. The ideas that he developed for achieving a visual expression of this equilibrium could be called his art concept.

Mondrian's way of thinking about art, along with that of Malevich and Kandinsky, influenced me in seeking and formulating my own art concept. Eventually I came to work with the extremes of visual opposites within one and the same painting field. These elements were shaped by the extremes of control and uncontrol.

Meanings and Interpretations

The present works represent the apparent polarities of human experience—the rational and the irrational, body and spirit, life and death, heaven and earth. Both in the paintings and in human experience we find that a radical polarity generally implies an opposite: dark implies light or conversely light implies dark.

The works, as a visual dialectic between control and uncontrol, embody an idea about how to make art. They also represent the spiritual struggle of life itself. One learns that peace and unity lie in the balance between reason and feeling—between all those interior forces that push and pull us in opposite directions. These works seem related to the traditional Chinese wisdom imaged in the yin/yang, woman/man, moon/sun, soft/hard, earth/heaven.

The Software Equivalent

In order to translate an art concept into software one first describes specific art-making procedures. This is achieved by thinking through each step. For example, if the procedure begins with drawing a line, then all the line-drawing factors must be identified. This includes the starting point, the basis for color decisions, the quality and character of the line, the direction the line takes (and factors that change the direction) and the length. Once these steps are understood they can be translated into software. The software code is a formal system equivalent to the art concept, an isomorphism to it in a computer language.

A similar isomorphism lies at the heart of D. Hofstadter's book *Godel, Escher, Bach: An Eternal Golden Braid.* In discussing how one can view a formal system both typographically and arithmetically, he notes that

> typographical rules for manipulating *numerals* are actually arithmetic rules for operating on *numbers.*
>
> This simple observation is the heart of Godel's method, and it will have an absolutely shattering effect. It tells us that once we have a Godel-numbering for any formal system, we can straightaway form a set of arithmetical rules which complete the Godel isomorphism. The upshot is that we can transfer the study of any formal system—in fact the study of *all* formal systems—into number theory [2].

To reiterate, if we can describe the procedures for expressing an art concept, then we can code those procedures and work with them arithmetically. The description of an art concept is essentially an outline of the decision system that governs the art-making procedures. We outline why, how and where we prefer to draw lines or paint areas. We identify the basis for how we scale relationships, choose colors and arrange the pictorial elements within the work. We describe the conditions of acceptable and unacceptable combinations of shape, scale and color. When these steps have been done in a thoroughly systematic way, we have described a formal system that can then be coded.

My program Hodos, which is continually under revision, represents an

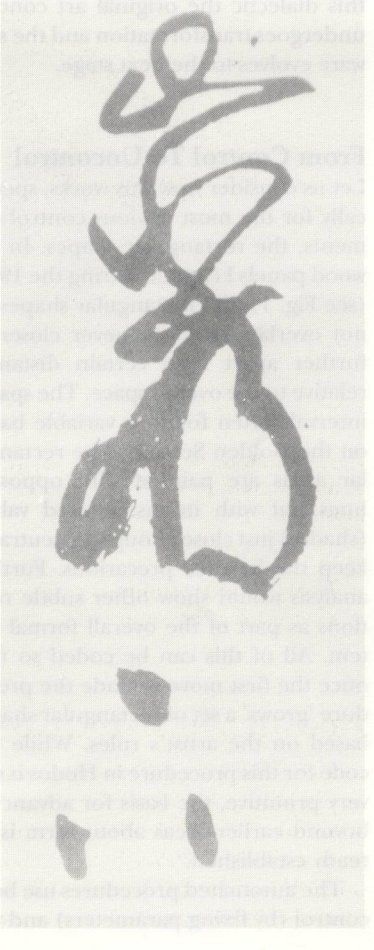


Fig. 4. An example of Chinese calligraphy in the *cao shu* 'grass writing' style by Zhang Xu of the Tang period. The text reads *yan xia* 'under the cliff'.

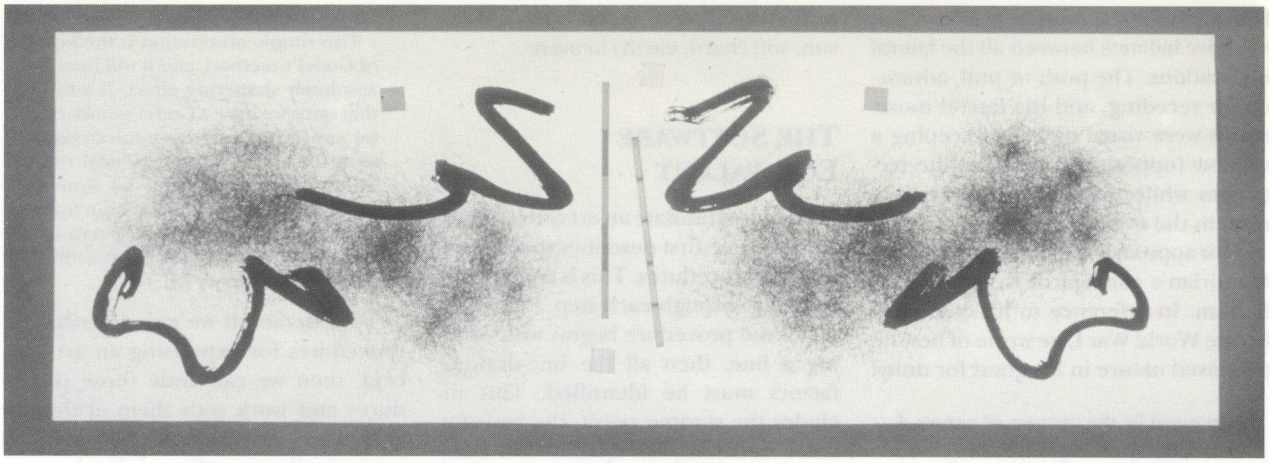


Fig. 5. Epigenetic painting, ink on rag paper, 2 × 6 ft, 1989. The artist's software, Hodos, was used. The work was executed with a 14-pen Houston Instruments DMP 51 plotter attached to an IBM PC. The brush strokes were made by the program with Chinese brushes adapted to the plotter.

advanced stage of a formal system translated into software. Still, there always exists a gap between theory and practice. While the software embodies essential art concepts, the process is still somewhat primitive. There are tested routines remaining to be integrated, and many more still to be developed. The process never ends. One reaches a plateau that provides the viewpoint from which one then sets up operations to attain the next plateau. By means of this dialectic the original art concept undergoes transformation and the software evolves to the next stage.

From Control To Uncontrol

Let us consider how this works, specifically for the most obvious control elements, the rectangular shapes. In the wood panels I created during the 1960s (see Fig. 1), the rectangular shapes do not overlap; they are never closer or further apart than certain distances relative to the overall space. The spatial intervals often follow a variable based on the Golden Section. The rectangular areas are painted with opposing hues but with intensities and values (shades) just close enough to neutral to keep the balance precarious. Further analysis would show other subtle relations as part of the overall formal system. All of this can be coded so that once the first move is made the procedure 'grows' a set of rectangular shapes based on the artist's rules. While the code for this procedure in Hodos is still very primitive, the basis for advancing beyond earlier ideas about form is already established.

The automated procedures use both control (by fixing parameters) and uncontrol (by selecting randomly within the parameters). For example, a 'starting point' routine may need several pieces of controller information such as preferred and forbidden starting areas. If one thinks of the pseudo-randomizing routine as 'tossing dice', then the procedure, in plain English, might reads as follows: "Find a valid starting point by tossing dice weighted for not more than a 25% deviation from a preferred starting area".

The artist, in the refining process, usually reviews scores of possibilities before making a software decision. By observation, the artist learns to adjust the routine and the data to achieve the desired formal effects. Following longer experience, the artist might see how one could again modify the algorithm to introduce variable scaling relationships that were not evident in earlier work. This feedback process provides for both refinement and growth.

We can do the same with every element that the art concept requires for building the work. For example, one of my line-drawing routines is coded to rotate randomly within certain parameters. The rotation parameters have been determined by my experience with what has worked and what has not. Still, the variables are changeable, and the default settings are revised from time to time. The software artist's work consists mostly of refining and developing routines for the program. Sometimes the slightest change of a routine opens up new vistas. The uncontrol elements that course through the program may be better understood by reviewing their sources and how they entered the work.

Uncontrol: Sources and Evolution

In the initial phases of the computer work, I sought to write a simple program just to sample the use of the computer as a medium—that is, just to get the computing process to generate the work. Step one was to make a scribble loop that would express the inner workings of the computer, similar to the way a Paul Klee doodle expresses the inner life of Paul Klee. That venture was not very successful, but it yielded insight into computerized automatic processes. Successful computer automatism would have to imitate 'automatic art', a genre of artistic activity that began early in this century.

Automatic art, tachism, and abstract expressionism are terms loosely associated with the idea that one can express something of one's psychic life, something that lies under, above or beyond conscious life, by working in a dreamlike or trancelike state. Such drawing, similar to doodling in an absent-minded state, was practiced by the Surrealists in the 1920s and even earlier by some of the Dadaists.

Both spontaneous gestural drawing and the Dadaist nonsensical juxtaposition of words employ techniques that step outside of rational procedure. Nonsense sounds, like nonsense drawing, were used in the Dada soirées to shock those who felt complacent with the power of reason. Some felt that if it was 'reasonable' to kill and be killed in the trenches of World War I, then perhaps nonsense should reign rather than reason. After all, some concluded, only political 'reasoning' made 'sense' out of the war.

Out of that artistic milieu came artists who learned to enter the frontiers of their inner world; through dreams and free associations, both artists and poets opened a new artistic frontier. My first computer efforts were simple routines to get the computer to mime some of these artistic forays that took place early in this century.

The Magic Hand of Chance

Eventually I came to focus on routines that mimed automatism with lines, shapes, colors, words, syllables and even sound. I filled literally scores of disks with draw routines, lexicons and poet routines for writing free forms, haiku and title lines.

My first exhibition piece, *The Magic Hand of Chance,* was exhibited on a 25-in monitor cabled to a personal computer. The program worked in real time, generating a series of six visual improvisations displayed in dynamic sequence on the monitor. These works, as nonrepetitive improvisations, evoked the kinds of surprises that emerge from free association.

The routines included *The Sayings of Omphalos,* the Greek word *omphalos* ('navel') being the name of my computer. The title alludes to the sayings of Mao Zedong. They have the form of Wisdom Literature, but they are actually playful nonsense pieces. An occasional juxtaposition of terms may shock us, as in free association, altering our viewpoint. Here is an example of the sayings (Appendix A has several more). *Omphalos on Prank:/The weak prank/regularly pricks;/Ponder blindly/ before prank stains.*

The program also has self-titling routines that generate original improvisational titles for each sequence. Some examples: *Instantly Frayed Whimsy; Lunkhead Thrills Iceman; Your Joyous Alarm; Bad Egg Brews.*

The most nonsensical of these routines is Jabberwock, which is part of a larger program. The program titles a subject of discourse and then proceeds to write a paper. Here is some Jabberwock work written on 1 September 1988. Jabberwock titled its subject *Enkaom Suxe Ilib.* The first paragraph reads:

> Schusca umopoh. Efet enkaom ku cuile oteoj yucou pnuibi suxe cu suxe. Ku ilib eey okoy oteoj uiyaurd autifib sciefio ilmedth. Qithi soraihio bu ghiahu sorio suxe. Sonua oray ultap enkaom ruweko suxe ku unuedum eg. Suxe ghiahu oden proveo ioyus ulmeuk.

Jabberwock and *The Magic Hand of Chance* provided the kind of logic from which the painting program grew. Eventually I became interested in hard copy and began to write software for building pictorial elements with lines and brush strokes.

Hodos

Lately this work has been most effectively realized in the program Hodos, which embodies the art concept described earlier. With a personal computer driving a 14-pen plotter, Hodos makes paintings that have a family resemblance to my earlier hand-painted work.

An outside observer, without knowing the techniques employed, might view them as a natural evolution in the hand of the artist. The automated techniques are so transparent that the viewer sees the artist's hand in individual lines and paint strokes. But the artist's algorithms work in lieu of the artist, and the plotter's arm works in lieu of the artist's hand. The technology frees the artist to concentrate creative energy on the next level of the dialectic.

Hodos, the title of the software, means 'path' or 'road' in Greek. Note that *meta-hodos* is the root of 'method'. The algorithms in Hodos describe paths that are the method for achieving the painting. Hodos as the path or the way is our Western equivalent of the Chinese term *dao* (*tao*), a key concept in ancient Chinese wisdom.

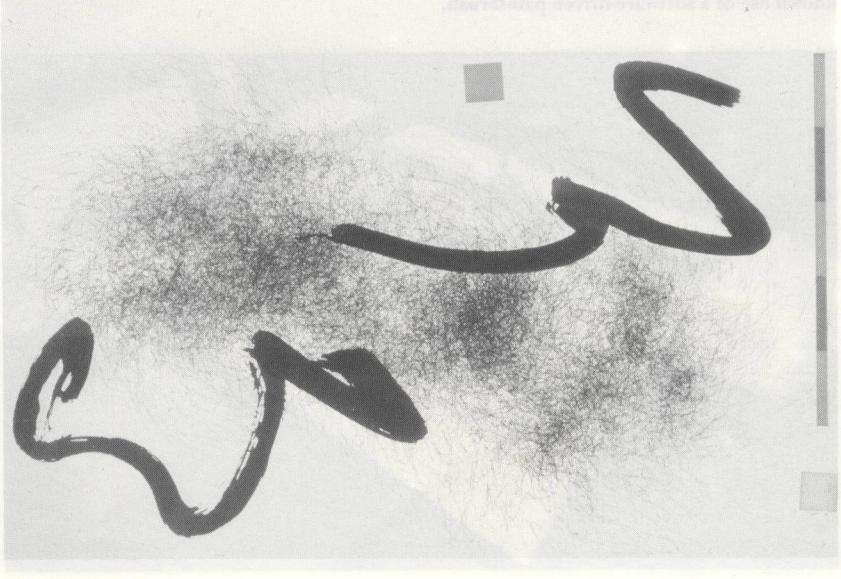
Some of the most recent works include brush strokes similar to those in Fig. 3. These works, entitled *Woo Way,* have some resemblance to Chinese traditional calligraphy. Fig. 4 shows a classic example of *cao shu* 'grass writing' by Zhang Xu of the Tang period. The text reads *yan xia* 'under the cliff'. Such calligraphy, still taught and practiced in today's academies, was practiced by Chan Buddhists and the literati.

The Hodos brush strokes represent an effort to achieve the fresh qualities of spontaneity and sureness of stroke. *Woo Way* is a word-play, an allusion to the Chan Buddhist wisdom of *wu wei* which means 'do nothing' and suggests letting nature take its course. It implies that one should not interfere with things but rather flow with the *way.* The computer gestures do not show the characters for *wu wei,* but perhaps the process itself is a form of *wu wei.*

The strokes follow whatever path the chaotic system makes. Whatever way unfolds in the context is just fine. A simple routine, similar to tossing dice, initiates the path. From then on the process has a remarkable life of its own following its own unique way. Figure 3 is a brush stroke sample demonstrating the character of one such pathway. Figures 5 and 6 show how such strokes have been generated by Hodos in works that include advanced forms of control and uncontrol.

While all the routines are automated, the default settings and data files are usually adjusted by the artist at start-up time. For a recent show, over 40 works were generated automatically with the same code (Color Plate B No. 1). The works bear a familial resemblance to each other and to earlier works, yet each one is original and

Fig. 6. Detail of Fig. 5.



unique. These features raise a number of new questions, which I examine following a discussion of hardware.

HARDWARE

Thus far, we have considered how an art concept can be coded when its formal system is described. Software in itself, however, is something like a musical score. The musical ideas are embodied in the score, but we cannot experience the music unless it is played on instruments. Similarly, the computer can be cabled to many different 'instruments'—printers, plotters, synthesizers, and telephones.

The Plotter

Usually my code is reviewed on a monitor. But the pixels on the monitor do not constitute paintings. While many artists get hard copy by photographing a monitor, some prefer to work with printers or plotters. A plotter is a drawing machine that can execute drawing instructions sent to it by a computer. Such machines are commonly used for architectural and engineering drawing.

Hodos is written to drive a pen plotter that has 14 pen stalls arranged in two banks with seven pens in each bank. Permanent inks, suitable for archival work, can be mixed by the artist. The program follows a set of rules about where to look for colors in a classical palette going from warm to cool colors. The program knows where to look for the pens, but the defaults can be altered by the artist.

My most recent work is executed on a white rag paper with a moderate tooth. The maximum frame size is 21.5 × 32 inches on a 24-×-36 inch paper. By running two frames lengthwise (36 in twice), one can easily manage a 6-ft work.

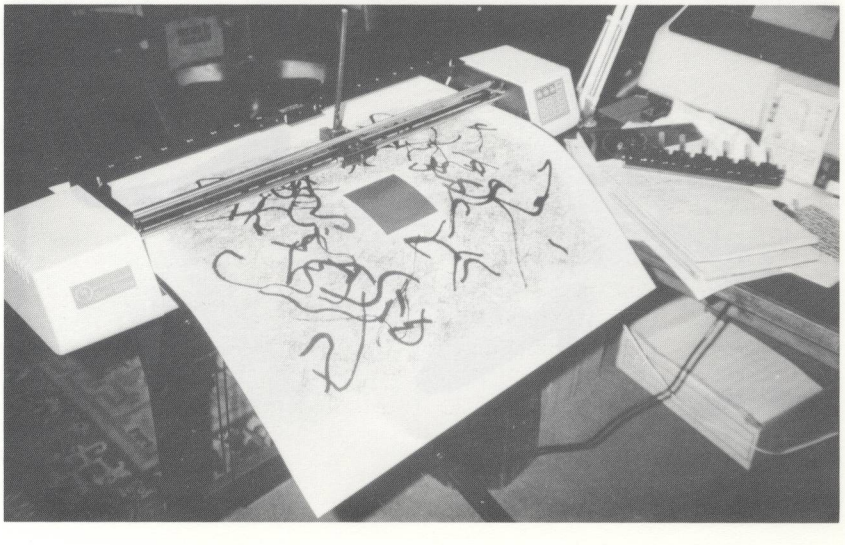
The technical pens range in size from '2' to '000' (.50 mm to .25 mm). They have refillable cartridges, so that it is possible to intermix inks for customizing the palette. Through experimentation I was able to make sleeves for mounting Chinese brushes on the plotter's drawing arm. Special paintbrush routines are integrated in the program for those paintings that require them. All pen routines are automated, so that the complete painting may be made without the artist being present. Although all brush strokes are automatically generated by the software, the mechanical limitation requires an assistant to hand the brush to the plotter on demand.

Figure 7 shows a Houston Instrument DMP 50 series plotter driving one of the adapted paintbrushes for the first time. The painting mounted on the plotter, executed on 12 December 1987, is believed to be the world's first brushed painting to have been realized automatically by an artist's software.

The Brushes

I felt somewhat foolish introducing this routine. I had spent long hours developing a routine to make the drawing machine paint with a brush. It seemed clumsy and almost pointless at first. But through trial and error with the brush mounts, the software, the inks and the paper, a vast untapped potential emerged.

Fig. 7. The plotter executing a brush routine on 12 December 1987; this was the first known use of a software-driven paintbrush.



With the software-driven stroke there is a sureness and directness that is almost exhilarating. The software knows precisely where beginnings and endings are. It remembers the stroke and can improvise with the same stroke in a scalar fashion and do so without failure. This latter capability promises rich ground for development.

Figure 3 shows a full-size stroke (reproduced here at 40%) with a scaled-down version of the same information drawn with a pen. This software-generated version of a stroke was created entirely by the artist's software. Notice the spontaneous quality of the stroke and how it drags off softly in relation to the tooth of the paper on the upper right portion. This stroke has many of the same qualities that are valued in Chinese calligraphy (see Fig. 4). The stroke shows movement, response to paper texture, dry brush effects and sureness.

Choosing Hardware to Fit the Tradition of Drawing

Hardware that fits the artist's goal is as essential as the software, and it is central to the development of that software. The unique characteristics of a particular hardware provide an opportunity to enhance the final form of the artwork. The plotter serves the artist well in several ways.

First, one can use traditional papers that have desirable textures and are archival [3].

Second, the drawing pen executes the lines in the fashion of the drawing hand. Plotters follow vector graphic instructions directly, which means that lines are drawn from one point to another, simulating traditional methods of drawing. This method echoes the way we think as visual artists.

Third, the plotter can build color tones and drifting fields through multiple layers of lines. This physical overlapping forms a glazing of inks that gives a strong visual effect that cannot be achieved by the single layer of dots in raster graphics.

Fourth, most plotters accept up to 1,000 increments per inch. This high resolution permits very subtle nuances of movement that can match the qualities of gentle hand or arm movement.

CONSIDERATIONS FOR NOW AND THE FUTURE

Hodos introduces art-making procedures of a different order from tradi-

tional procedures. The closest analogy might be the score for a musical composition. Both the musical score and software art provide instructions for the creation of an artistic form. The traditional musical score, however, requires skilled players and provides the rules for playing only the same piece each time. Hodos requires no skilled players and can make a different work each time.

A process that can improvise on an artist's own formal ideas without the artist being present extends the power of the original art concept. For example, a colleague from a university some thousand miles away suggested that I send my software as a 'visiting artist' one semester.

What are the implications? Traditional technologies require that the artist must direct even the simplest improvisation on a print or a photograph. The change in exposure, color or light must be either made or directed by the artist. In software art, some of the artist's ideas about how to make improvisations are coded. This code extends the artist's ability to improvise or preview improvisational possibilities without apparent limits. Such power of improvisation provides the artist with an awesome leverage for exploring form-making ideas.

Familial Form

The stylistic commonality of works generated by the same software has a quality that can be called familial. This quality seems to hold for Hodos. My wife uses the same software, which is user friendly, i.e. allows for user choices and options. Data files for making paintings can be generated by the user. Using her own preferences within the optional parameters of Hodos, my wife can make one-of-a-kind works that we consider originals.

Her Hodos works have distinctive stylistic qualities that mark them as hers, yet they clearly belong to the Hodos family. The art concepts of the software artist tend to dominate the work even though the expert user's input may be unique and innovative.

Why, one might ask, is this matter of familial quality important? The reason is that traditional media have not had such a strong impact on style. A paintbrush has some effect on style but nothing like the influence of an expert system, which joins an author's ideas with technical execution. Software art, if we call it a medium, is an information-enriched medium with embedded ideas about form. These form-making ideas impart features to the works that the software generates. The parenting features are so remarkable that we are led naturally to look at a biological analogue.

A Biological Analogue

The process of making art with a personal expert system has a strong resemblance to the biological process of epigenesis. The epigenesis of organisms is the process whereby a mature life form unfolds or grows from its seed. In this analogy the software may be viewed as the genotype that contains all the information necessary for the mature form. In genetics the term epigenesis is used to describe the process whereby the phenotype (a physical organism) grows (unfolds) from a genotype (encoded on DNA). The analogous procedure for the paintings suggests that Hodos, the software, may be viewed as a genotype, the painting as a phenotype, and the process as epigenesis [4]. Software art has adequate information about how to grow a painting through a series of recursive graphic routines; each unfolded offspring is a variant of its predecessor. The analogy stops here, because these offspring cannot beget the next generation. They do point the way for the artist in designing the next generation of software.

Art-Making Systems

In summary, a new order of art-making system has been emerging. Feedback from a program helps the artist develop the next stage of software. The evolving program helps create itself much as machines have been used to make better machines. There are plateaus of sophistication. The evolving software is the new art, and it can be viewed as analogous to genetic code.

The software also has the potential for hybridization. For example, one might code an art idea of Wassily Kandinsky and a musical idea by M. P. Mussorgsky. One might then build a hybrid Kandinsky-Mussorgsky code. One could add audio and visual drivers for all or part of the code as desired. Eventually one could pair this art concept with another. Each frontier opens a new frontier.

Within the next decade or so advances in high-level software will make it possible for more artists to easily build their own personal expert systems. Familial form traits, like gene characteristics, will reside in the high-level software that artists use to make their own expert systems. Some inherited familial features will pop up in some works and not in others as artists learn how to get their own form preferences to prevail.

In a very uncanny way software appears to have a life of its own. The artist's role is to humanize it—to give it form and structure so that it may serve the quality of our art and of our life.

APPENDIX A: SAYINGS OF OMPHALOS

Omphalos on Age:
The tattered age opportunely wobbles.
Plow over whenever age chafes.

Omphalos on Sheik:
The rapid sheik rarely abdicates.
Cook wittily after sheik dissolves.

Omphalos on Road:
The road shoves warrior rapturously.
Seldom awful road pleases cryptogram.

Omphalos on Hole:
The noble hole consistently raids.
Cook skillfully even if hole caresses.

Omphalos on Virtue:
The lifeless virtue inopportunely breeds.
Manage ably whenever virtue scolds.

References and Notes

1. Piet Mondrian, "Towards the True Vision of Reality", in *Plastic Art and Pure Plastic Art and Other Essays*, 3rd Ed. (Wittenborn: Schultz, 1951) p. 15.

2. Douglas R. Hofstadter, *Gödel, Escher, Bach: An Eternal Golden Braid* (New York: Vintage, 1980) p. 264. Hofstadter's own interpretation of Godel appears important in understanding the artificial intelligence issues. Hofstadter's essential summary of the idea appears in Chapter 9, "Mumon on Godel". For Hofstadter the Zen ideas bear a metaphorical resemblance to some contemporary ideas in the philosophy of mathematics.

3. I have worked with Stonehenge, Arches, Magnani, Bienfang and Strathmore.

4. C. H. Waddington uses the term *epigenetic landscape* to illustrate his theory of evolving patterns in organic life—C. H. Waddington, *The Strategy of Genes* (London: George Allen and Unwin, 1957). The illustration and its implications have been discussed by P. T. Saunders in his article "The Evolution of Form and Pattern", *Leonardo* **22**, No. 1, 33–38 (1989). The discussion reinforces the notion that a family of forms generated by the same algorithm follows a process similar to epigenesis.

Visual Mathematics

The editors of *Leonardo* invite artists and scientists to submit papers and manuscript proposals on the subject of "Visual Mathematics". A special issue is planned, with Guest Editor Michele Emmer.

Visualization has been of great importance throughout the history of mathematics. Many mathematical 'visual' ideas have been important for artists, as well. Recently, mathematicians have enlarged the world of visual mathematics by the use of computer graphics, but the planned special issue will not focus on this subject alone. The aim is to point out the various aspects of visual mathematics, including methods for creating a large range of new forms and shapes, a new universe of mathematical images, spanning all possible media, from drawings to computer graphics. The issue will also focus on aesthetic aspects: mathematicians proposing themselves as artists, and artists using visual mathematical ideas.

The point of view of art historians, as well as other historical aspects, will be addressed. Special attention will be paid to the last century, without, however, excluding contributions from earlier times.

Papers by scientists should not be merely descriptive but should investigate and explain the mathematical techniques involved.

Papers by artists should point out how visual suggestions from mathematics have influenced the artist's work.

Papers explaining how visual input from art has been useful in mathematics are encouraged.

The special issue will also contain reprints of relevant historical documents written by artists, art historians and scientists.

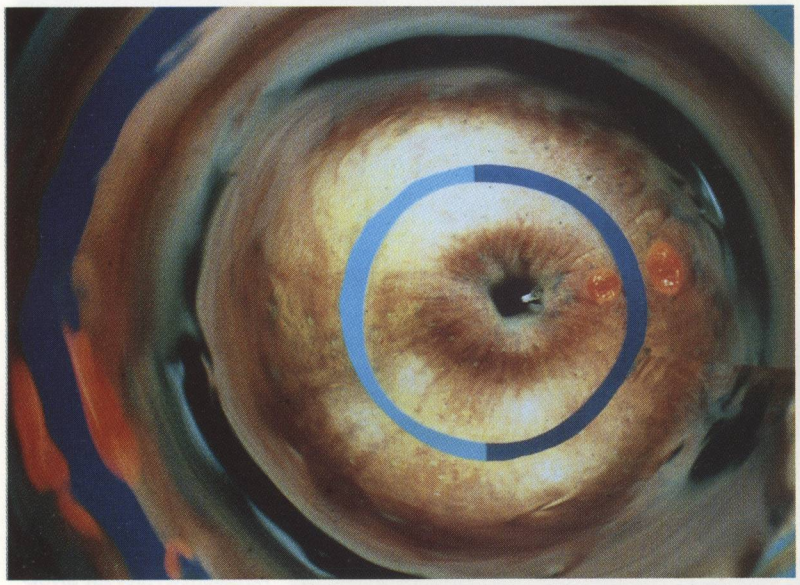
This issue will not be a collection of mathematical forms and shapes but instead will focus on visual ideas that have been of importance separately for mathematicians and for artists and sometimes for both professions.

It is the Guest Editor's intention to dedicate this special issue to David Brisson.

The deadline for manuscript proposals is 1 July 1990. Manuscripts, proposals and inquiries should be sent to Michele Emmer, Dipartimento de Matematica, Universita Di Roma, Piazzale Aldo Moro, 2, 00185 Roma, Italy.







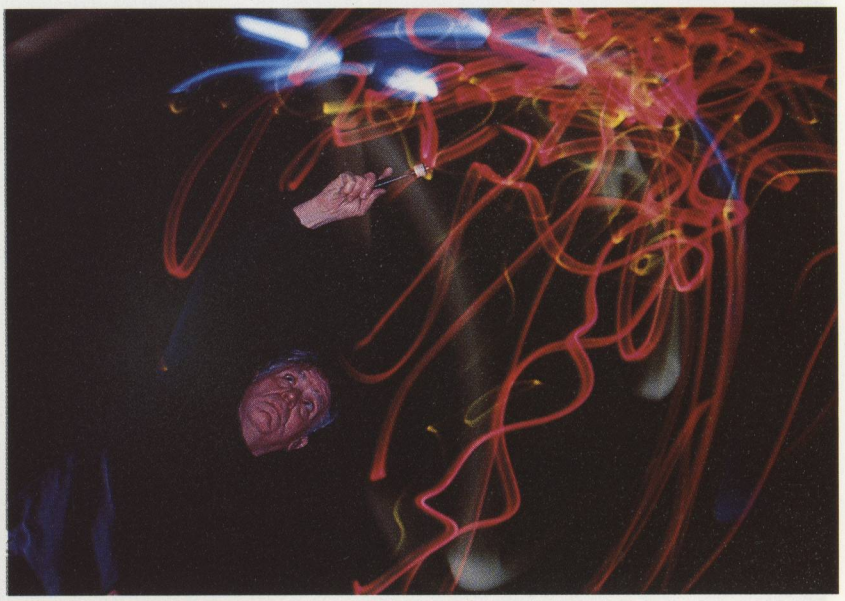
COLOR PLATE A

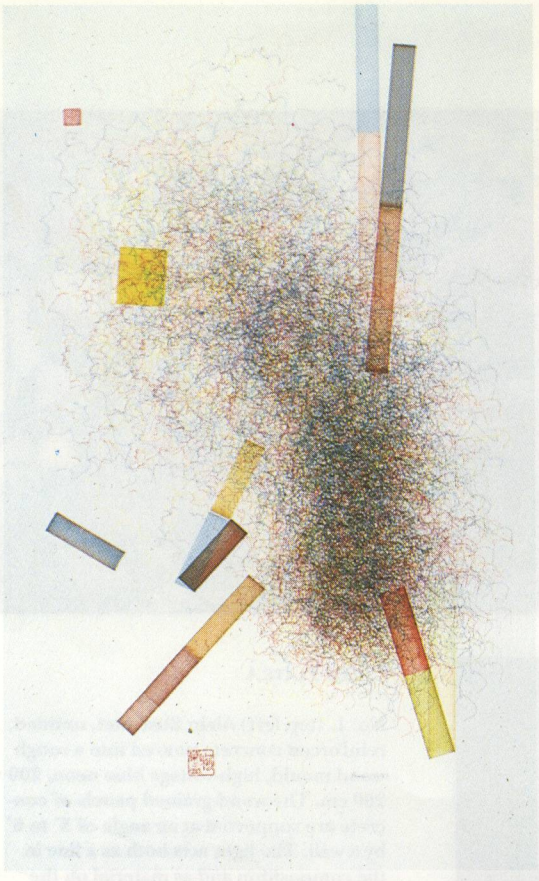
No. 1. (top left) Alain Buscarlet, untitled, reinforced concrete poured into a rough wood mould, high-voltage blue neon, 200 × 200 cm. The wood-grained panels of concrete are supported at an angle of 5° to 6° by a wall. The light acts both as a line in the composition and as material on the wall, totally enveloping the structure with a halo of light from behind.

No. 2. (top right) Yuan Yun-Fu, *History: Yesterday—Today—Tomorrow*, hand-woven silk tapestry, 6.5 × 8 ft, 1987. This work expresses the traditions of Chinese art and technology as well as innovations and progress in the fields of electronics, human biology and space aeronautics, both present and future.

No. 3. (above) Naomi Asakura, color photograph of an apple on light blue, dark blue and shaded blue paper reflected onto the inside of a cylindrical mirror.

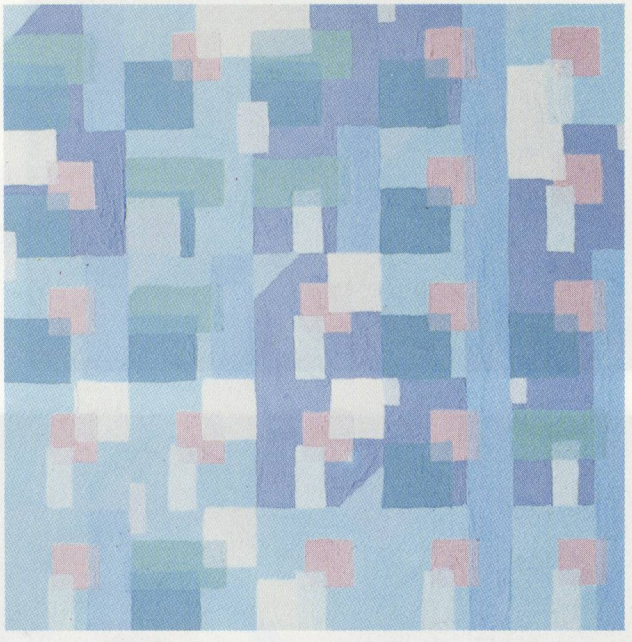
No. 4. (right) Robert Mallary, stereoscopic sculpto-painting, 1988. The author has been caught by a flash unit while in the process of creating a stereoscopic 'light event' in his studio. Initially inspired by Gjon Mili's famous strobe photo showing Picasso drawing in space with a penlight, the process is being developed into a stereoscopic form of sculpto-painting for computer processing and enhancement.





COLOR PLATE B

No. 1. (left) Roman Verostko, epigenetic painting, ink on rag paper, 2 × 3 ft, 1988. The same process used in Fig. 5 (see Artist's Article) was used without the brush routine. All pen strokes and solid areas were automatically executed by the program without stopping.





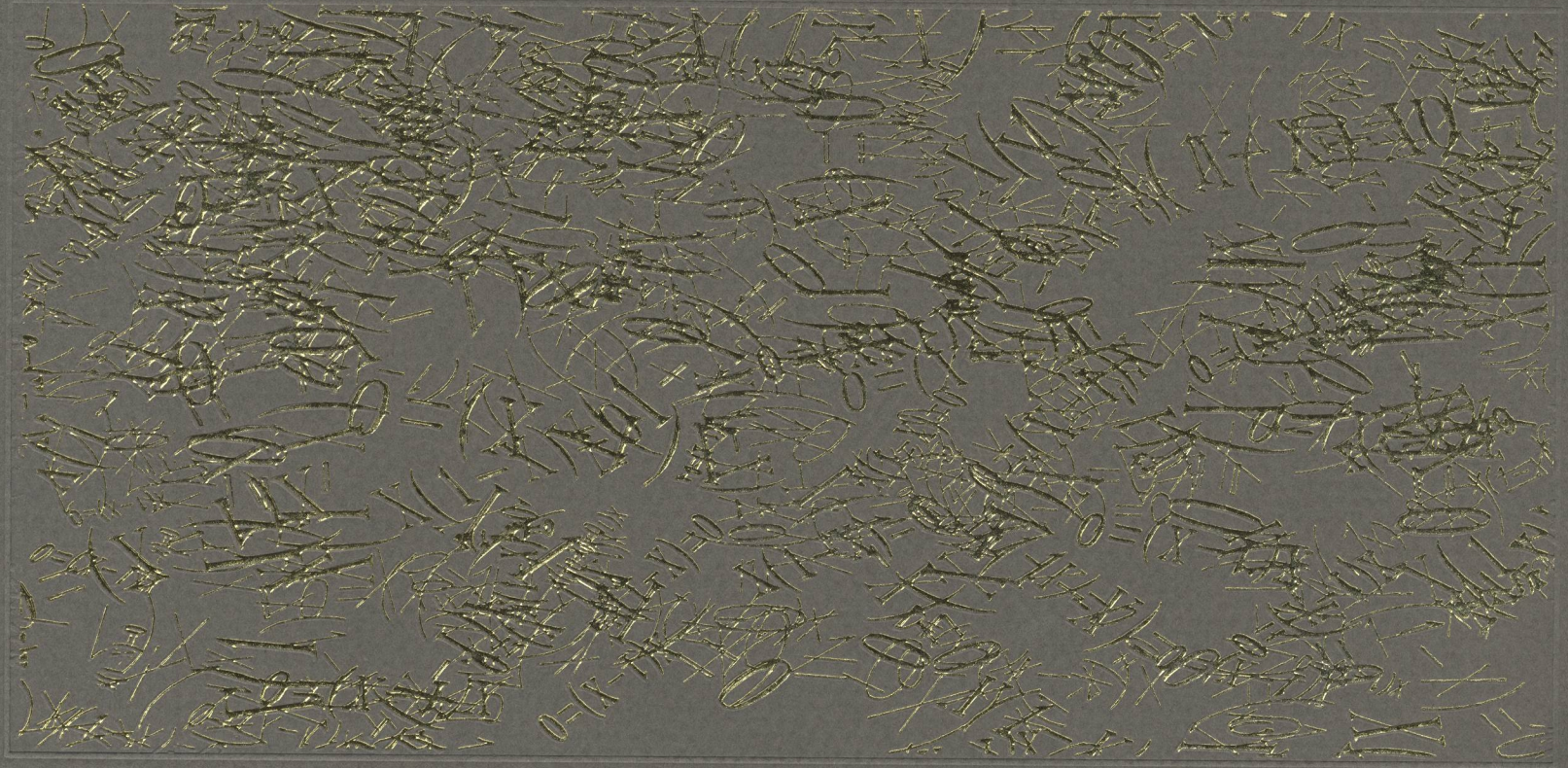
No. 2. (above) Lisa Hartjen, untitled, gouache on paper, 7.5 × 7.5 in, 1986. Basic design and randomness project (see General Article by Michael Eckersley). This foundation-level design project involved variables of shape, placement, color, transparency and overlapping of shapes. Each student formulated rules for invoking particular shapes and colors. Issues of placement, transparency and overlapping were randomly determined using a deck of cards.

No. 3. (left) Ronald Brown and Gary Burgess, color photograph, 1976. This image shows the visible light spectrum of helium gas excited in a high voltage electric discharge tube and photographed using a diffraction filter.

G 175

Derivation of the Laws

Boole



Verostko

Computer Illustration





DERIVATION OF THE LAWS OF THE SYMBOLS OF LOGIC FROM THE LAWS OF THE OPERATIONS OF THE HUMAN MIND

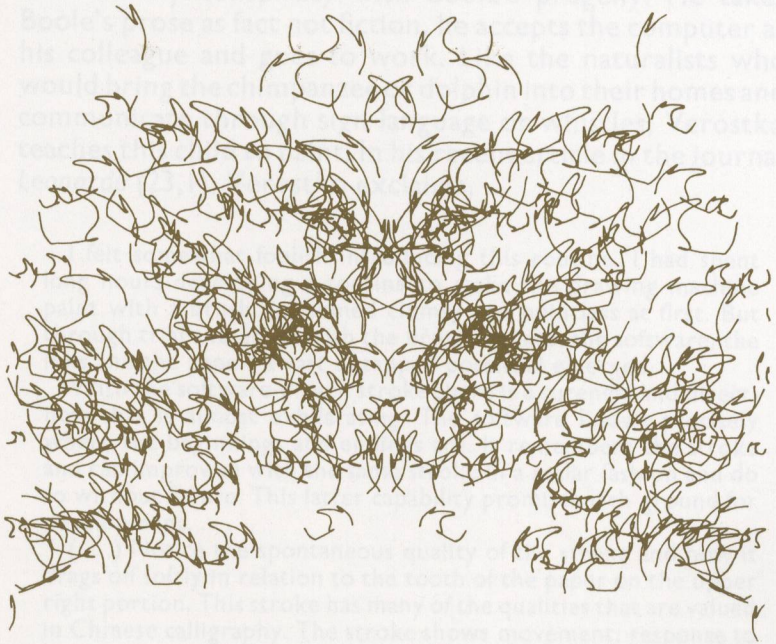
An excerpt from the writings of George Boole : : Computer illustration by Roman Verostko : : Preface by Roger F. Malina

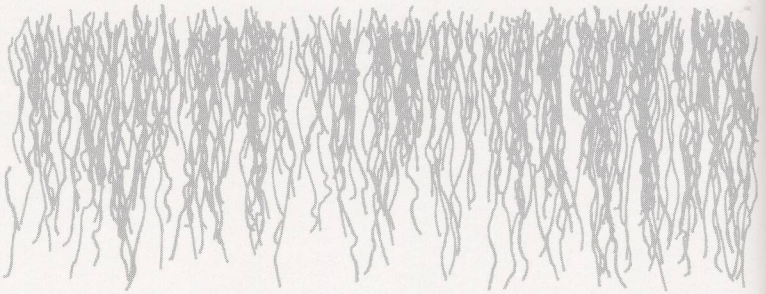
St. Sebastian Press Minneapolis 1991

CHAPTER III. "DERIVATION OF THE LAWS OF THE SYMBOLS OF LOGIC FROM THE OPERATIONS OF THE HUMAN MIND," from *AN INVESTIGATION OF THE LAWS OF THOUGHT ON WHICH ARE FOUNDED THE MATHEMATICAL THEORIES OF LOGIC AND PROBABILITIES* by George Boole, L.L.D., was first published in London, 1859 by Macmillan.

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Derivation of the laws : derivation of the laws of the symbols of logic from the laws of the operations of the human mind : an excerpt from the writings of George Boole / computer illustration by Roman Verostko : preface by Roger F. Malina.
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Preface

Mathematics, as the Queen of the Sciences, has long had a tempestuous relationship with working artists and scientists. One of the mysteries of this relationship is that the constructs of logic and mathematics are found time and time again to have a privileged relationship with respect to the real world.

There have been times when the beauty of a logical or mathematical idea has led artists and scientists astray. For there is no rule that the real world must meet our transient standards of beauty. It was trial and error, not theoretical constructs, that led finally to the sublime creations that are

the great cathedrals of Europe. And a new age undid the beautiful machinations of Aristotle with the power of observation. Many a bridge and ship, dreams of nineteenth-century engineers, collapsed under the weight of the new and poorly understood materials of an optimistic age.

In this century Theodore Von Karman, one of the greatest applied mathematicians of all time, brought the nineteenth-century engineer into check by reasserting principled alternatives to trial and error and the engineers' rule book. Von Karman, together with my father Frank J. Malina and a group of graduate students, demonstrated that even the behaviour of explosives and rockets is susceptible to the charms of the Queen of the Sciences.

We live in a time when mathematics is at its prime as a device—a tool—for perception, understanding, and mastery of the world around us.

II

This is a book about trial and error. George Boole, with the supreme confidence of his century, assures us that he has no truck with metaphysics: "As respects both the determination of the laws of thought, and the practical uses of them when discovered, we are, for all really scientific ends, unconcerned with the truth or falsehood of any metaphysical speculation whatever."

Roman Verostko, with the doubt of a doubting century, is in unholy conspiracy with Boole's progeny. He takes Boole's prose as fact not fiction, he accepts the computer as his colleague and goes to work. Like the naturalists who would bring the chimpanzee or dolphin into their homes and communicate through sign language or whistles, Verostko teaches this child to paint. In his recent article in the journal *Leonardo* (23,1), Verostko exclaims,

> I felt somewhat foolish introducing this routine. I had spent long hours developing a routine to make the drawing machine paint with a brush. It seemed clumsy and pointless at first. But through trial and error with the brush mounts, the software, the inks and the paper, a vast untapped potential emerged.
>
> With the software-driven stroke there is a sureness and directness that is almost exhilarating. The software knows precisely where the beginnings and endings are. It remembers the stroke and can improvise with the same stroke in a scalar fashion and do so without failure. This latter capability promises rich ground for development. . . .
>
> (. . .) Notice the spontaneous quality of the stroke and how it drags off softly in relation to the tooth of the paper on the upper right portion. This stroke has many of the qualities that are valued in Chinese calligraphy. The stroke shows movement, response to

paper texture, dry brush effects and sureness.

Elsewhere, Verostko notes that "the computer gestures do not show the [Chinese] characters for *wu wei*, but perhaps the process itself is a form of *wu wei*." Verostko, if he were a computer scientist, would have described this statement about the painting as the assessment of a Turing test, a test where an unknowing observer is asked to distinguish the task performed by a computer from that performed by a human being. Inevitably on the pages of this book, the work of an artist qua computer scientist confronts George Boole with his hidden metaphysics, his *wu wei*.

III

My son, Xavier, is two years old. In the evening, whilst I cook dinner, he likes to be with me in the kitchen. He sits at the table drawing and painting. He is still at the stage of unformed scribbles, scribbles that he tells me signify equally well a dinosaur, San Francisco, or a train.

I have been trying to teach him that although paint tastes and feels interesting, it is only the visual qualities of paint that are to be valued. When I draw the round outline of a circle which I call "big moon," he tries to copy me. He draws a respectable circle by now. His memory is good, but he often does not remember the new shapes I taught him yesterday.

I am angry at Xavier whenever he paints on the wall next to the table or on the kitchen floor. I try to teach him the hidden meaning of the edge of a piece of paper. Sometimes he keeps drawing on the same piece of paper until it is a solid mass of paint, with no sense of order or pattern. With repetition, he is beginning to exert some discipline over the lines on the paper.

While I cook and he draws, we talk to each other. His attention span is not very long yet, so he loses interest, climbs on a stool, and starts playing with the water in the sink. Eventually, I much teach him the danger of instant gratification and the value of anticipation.

IV

The computer understands words so easily, but not sounds, smells, sights, or textures. It remembers so easily, that we struggle to introduce spontaneous and unpredictable responses. It never bores of repeating the same task endlessly. It does not understand ambiguity or small talk, and the only surface it draws on is the one we have told it

about. It has a vast memory and remembers yesterday's lesson as well as last year's.

Yet, as with a child, we willingly spend hours and hours teaching it the things that will please us and the things that will keep it content. One day computer education will not mean how you teach people to use computers but rather how people should teach computers to grow up.

There is a large literature analyzing the history of technology and its role in human society. We are reminded that we have invented tools to extend or augment our own senses and faculties. The telescope and microscope extend the range of our eyes. In similar ways we have found means to extend and amplify as well our other senses: hearing and touch, taste and smell. With books, films, recordings, and computer disks we have augmented our memory. With automobiles, airplanes, and spaceships we have extended our mobility. With drugs, diets, and medicine we seek to extend our life span.

The computer, if viewed as a living organism, has an evolutionary advantage over our own species. Each generation of computers is much shorter than a human generation, so computer evolution is occurring much more rapidly than human evolution. Computers are mutating and adapting to a changing environment and changing needs.

The computer, as a living organism, started off with the technologies that we had developed to extend and amplify our own senses and capabilities, and we continue to connect computers to new tools as fast as we can invent them. The future of computer evolution will involve the acquisition of features that are inherent to us as humans. Computers will be taught to become self-repairing, self-replicating, and adaptable. The computer in a sense is still in the Garden of Eden, and the hand of the creator is still omnipresent and all powerful. The computer is still made in our own image, and its evolution will continue for some time to encompass more and more human traits.

For independent evolution to occur, computers eventually will need to find a different evolutionary niche—to be expelled from the territory that we both now occupy. This is all perhaps too fanciful, but the drawings in this book force me to such musings—and make the road from George Boole to metaphysics seem all too short.

V

I am a working astronomer involved in a project to map the sky in the extreme ultraviolet part of the spectrum. The sky has never been mapped in this color of light, and the

human eye is unable to detect it. This light never reaches the ground because it is blocked by the atmosphere of the earth. New telescopes are uncovering a universe largely beyond the scientific speculation of earlier days, when we were confined to the universe that could be observed only in the visible part of the spectrum. We find new parts of the universe in X rays, radio waves, infrared light, extreme ultraviolet light, and all the other parts of the spectrum inaccessible to the human eye. There have been many connections between the discoveries of astronomy and the philosophical systems we have invented. With each new part of the universe discovered by contemporary astronomers, humanity's place in it is subtly changed.

As we equip the computer with new interfaces, whether a brush or a hypercard, the place of the computer is redefined, just as each new map of the sky reveals a new context for viewing ourselves. The artist, as much as the computer scientist, has a key role in developing the interfaces of the computer and hence in defining what it means to be a computer.

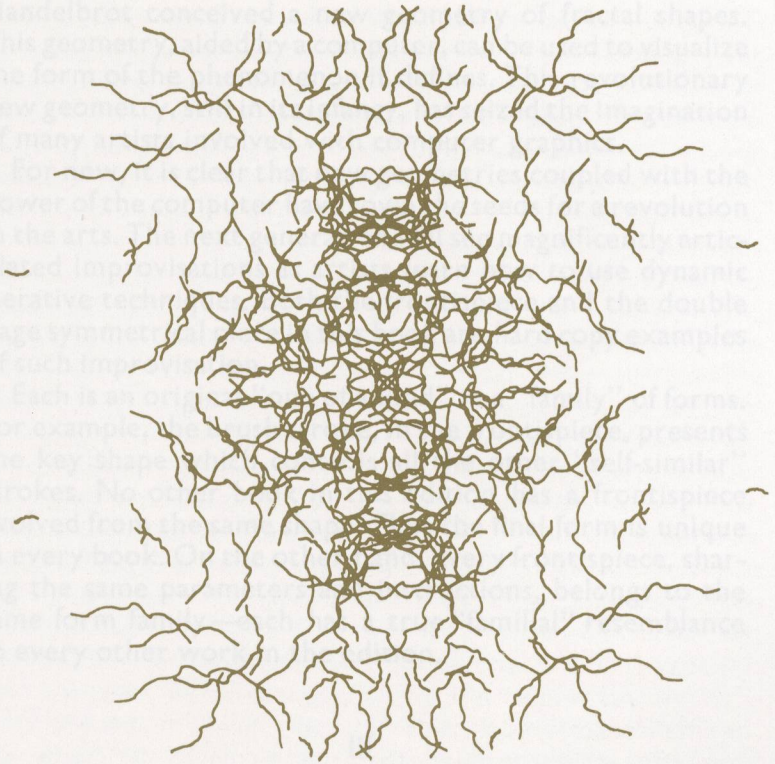
Today is also a time when our respective understanding of the universe on the largest scale, as cosmologists, and on the smallest scale, as particle physicists, are joined together. These connections are made through the mathematical bases of physical laws established over the past few centuries.

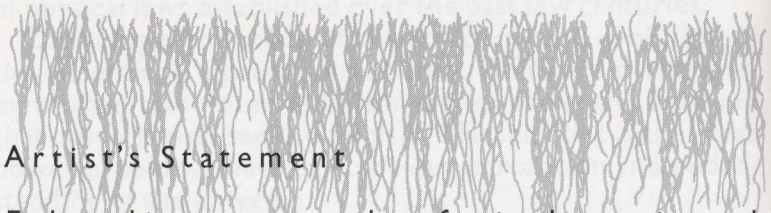
Cosmology, the study of the structure and evolution of the universe, is a precarious science. There are perhaps no more than two dozen established facts about the universe that cosmologists seek to explain. Mathematics is the most powerful tool we have to guide our perception and understanding of the universe.

New mathematical systems lead to new conceptions of the universe, whether formulated and applied in the day of Aristotle, Copernicus, or Einstein. Today's computer is heir to work of mathematicians such as George Boole and Alan Turing. Already we see new kinds of computers being developed based on different internal architectures and mathematical descriptions. Artists, with computer scientists, must be involved in developing the cosmologies associated with each of these different kinds of computers.

Whatever the roles played by artists in this "postmodern" era, they surely include working side by side with scientists, engineers, and mathematicians in the effort to connect fact and theory within the realm of human understanding.

Roger F. Malina
Oakland, March 1990





Artist's Statement

Early in this century a number of artists became intensely interested in unfolding a universe of visual form which did not "re-present" the world we see around us. Wassily Kandinsky strove to create "improvisations" based on "inner necessity," something like the structure of harmony in music. Paul Klee observed that he wished to "make visible the invisible"—perhaps the process of a flower blooming. And Piet Mondrian sought a "dynamic equilibrium" through the visual equivalence of opposites—an opposition he observed most profoundly in the relationship of the vertical and the horizontal elements in the landscape. These and many others—Frantisek Kupka, Kasimir Malevich and the pioneering constructivist brothers Naum Gabo and Antoine Pevsner—all shared one thing in common—they sought to make visible a reality which was not visible.

Each in his personal way searched for forms which some have called the "new reality"—a world of forms without

reference to the visual vocabulary of our everyday world. Terms such as "non-objective art," "concrete art" and more generally "abstract art" have been used to refer to this work. Within the first generation of these artists, we have experienced many marvelous moments: recall the lyrical biomorphic forms in the sculpture of Jean Arp—the vibrating power of interacting colors in the work of Joseph Albers and Victor Vasarely—and the expressive wonder in the organic worlds sculpted by Isamu Noguchi.

II

Within the past fifteen years, experiments with hidden worlds of visual form have crossed a new threshold. The pioneers who opened our eyes to these forms have been mathematicians and physicists whose images of complex dynamic systems have amazed the discoverers themselves.

This new world of visual adventure, which lay largely unseen before computers, received its first unveiling in the work of Benoit Mandelbrot. Surprisingly this hidden world emerged from the need for a geometry for measuring and describing the forms of nature. How do we describe mathematically the shape of a cloud, a coast line, or a mountain? Not with the cones and spheres of Euclidian geometry! Mandelbrot conceived a new geometry of fractal shapes. This geometry, aided by a computer, can be used to visualize the form of the phenomenon it defines. This revolutionary new geometry, still in its infancy, has seized the imagination of many artists involved with computer graphics.

For now, it is clear that new geometries coupled with the power of the computer have sown the seeds for a revolution in the arts. The next generation will see magnificently articulated improvisations as artists learn how to use dynamic iterative techniques. Both the frontispiece and the double page symmetrical piece in this book are hard copy examples of such improvisation.

Each is an original "one of a kind" in a "family" of forms. For example, the brush stroke, in the frontispiece, presents the key shape which controls all the other "self-similar" strokes. No other book in this edition has a frontispiece evolved from the same shape. Thus the final form is unique in every book. On the other hand, every frontispiece, sharing the same parameters and instructions, belongs to the same form family—each has a true "familial" resemblance to every other work in the edition.

III

There are many remarkable analogues between computing processes and biological processes, e.g. software generations, computer viruses. We can expect these analogies to become more apparent as computers evolve further. We assume that the "rulebook" in our universe is the same for every information processing system whether it be the mind of a human or a chimpanzee, an abacus or a Disk Operating System (DOS).

This "rulebook" fascinated George Boole. He was convinced that if the laws of logic "are really deduced from observation, they have a real existence as laws of the human mind independently of any metaphysical theory. . . ." He sought to identify those rules of thought and give them algebraic expression.

In Proposition IV he identified "the fundamental law of thought" as Aristotle's principle of contradiction—that "it is impossible for any being to possess a quality and at the same time not to possess it." George Boole argues from its algebraic equivalent that "what has been commonly regarded as the fundamental axiom of metaphysics is but the consequence of a law of thought, mathematical in its form."

From this foundation he evolved a symbolic logic for the "essential laws of human language." He achieved the first successful application of algebraic methods to logic, an achievement which provided the foundation of all subsequent developments in the field. "Boolean" Logic, refined by his successors and essential to switching theory, has been the cornerstone for developing the circuitry and software for the modern computer.

If George Boole were living today he would stand in wonder and amazement pondering the magnificent machine language that has evolved since the publication of the *Laws* in 1854. I think especially that he would be transported to near ecstasy seeing the binary 1's and 0's in computer assembly language which symbolize the "on" and "off" bits. This is his Proposition IV evolved into a machine language that controls the electronic circuits in everything in our daily world from cash registers, airplanes, and washing machines to Cray supercomputers.

The illustrations in this book have evolved from procedures made possible by Boolean logic. For several illustrations I adjusted my algorithms to use terms from Boole's symbolic logic for the graphic improvisations. In those cases the 1's and 0's were distributed randomly around a center of attraction. The visual effects are intended to suggest the dynamism inherent in logical systems. It is a tribute to Boole who perceived the value of a symbolic language of logical equivalence in advance of computer languages.

IV

As a final note I want to place this work in historical context. In the early 15th century Filippo Brunelleschi developed linear perspective and Leon Battista Alberti documented its theory and practice in his work *Della Pittura* (1435). The perspective of the 15th century was more than a re-tread of the perspective practiced in the Roman empire. Alberti's treatise emerged along with the growth of empirical observation as a *learning method* and an interest in the study of optics as a key to that learning.

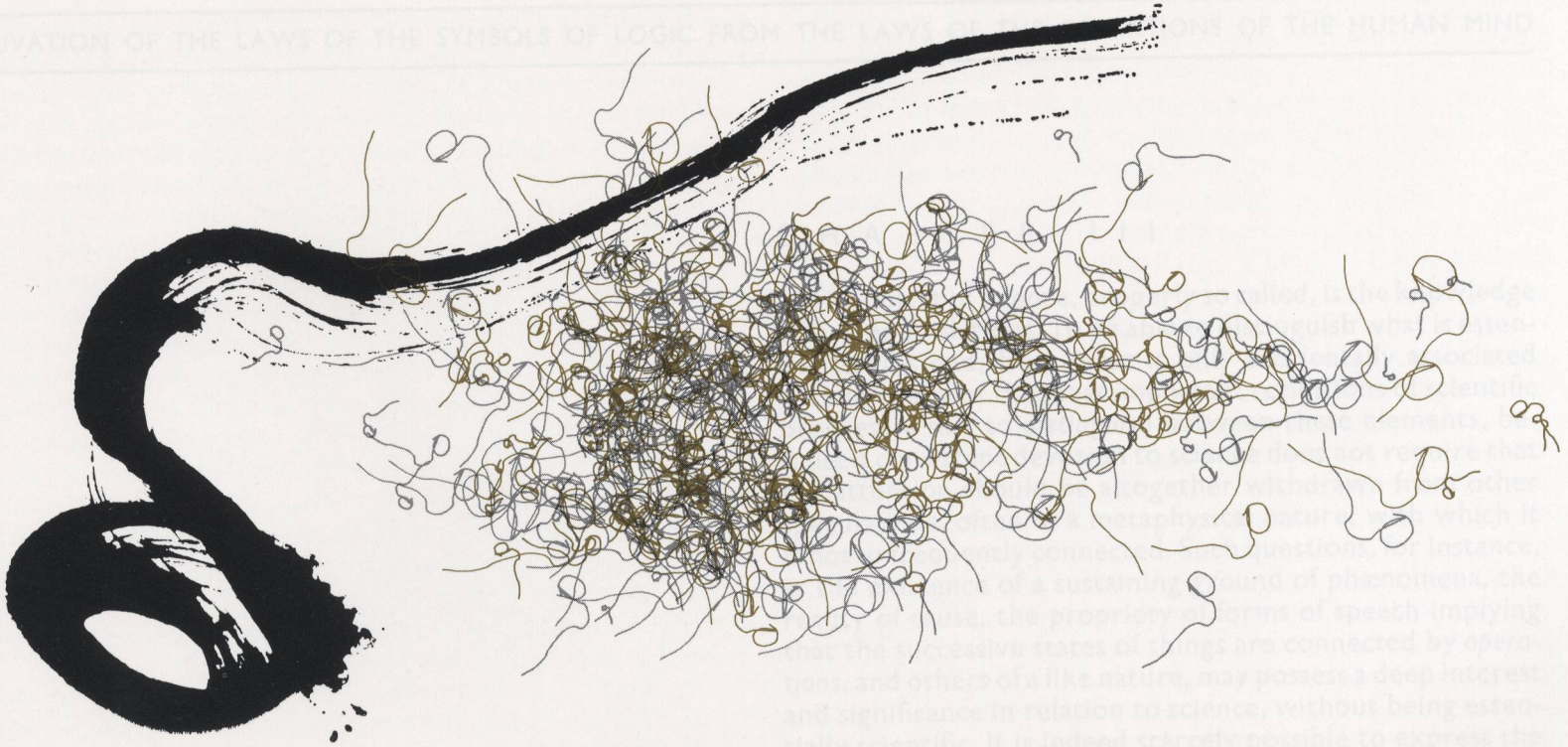
Furthermore, Alberti believed that mathematics and logical order were essential for the practice of art. Subsequent development in the theory and practice of perspective altered the art of western culture. Indeed, Renaissance perspective provided the tools of visualization essential for the development of modern western civilization.

I think that we stand at a similar threshold today as we face the future. The computer provides the artist with a seemingly limitless power to transform and improvise. And, like Renaissance perspective it provides us with a new window on our world —one that is altering the way we perceive that world.

Over the years I have gained a respect (and even affection) for the machines I use. My plotters, named Alberti and Brunelleschi, are with my computer, my excellent companions in exploring these new perspectives. They help me explore visual analogues of probability, forms which were hidden from view before we had these machines. Through the computer we have gained access to a visual domain filled with mystery, a domain that was invisible before. For many the energy and growth patterns of these forms echo processes lying at the core of the unfolding universe. My work explores a faint echo of this cosmic landscape. For me, the computer and its companion plotters provide a new pathway to "making visible the invisible."

Now, in the summer of 1990 we recognize that electronic art is still in its infancy. But, as in the early 15th century, there are artists now wrestling with the problems of the transformation and creation of art forms with computers. The new geometries and new technologies will surely bring a revolution as we approach the next century. This book is a tribute to George Boole whose work helped make this new adventure possible.

Roman Verostko
Minneapolis, June 1990



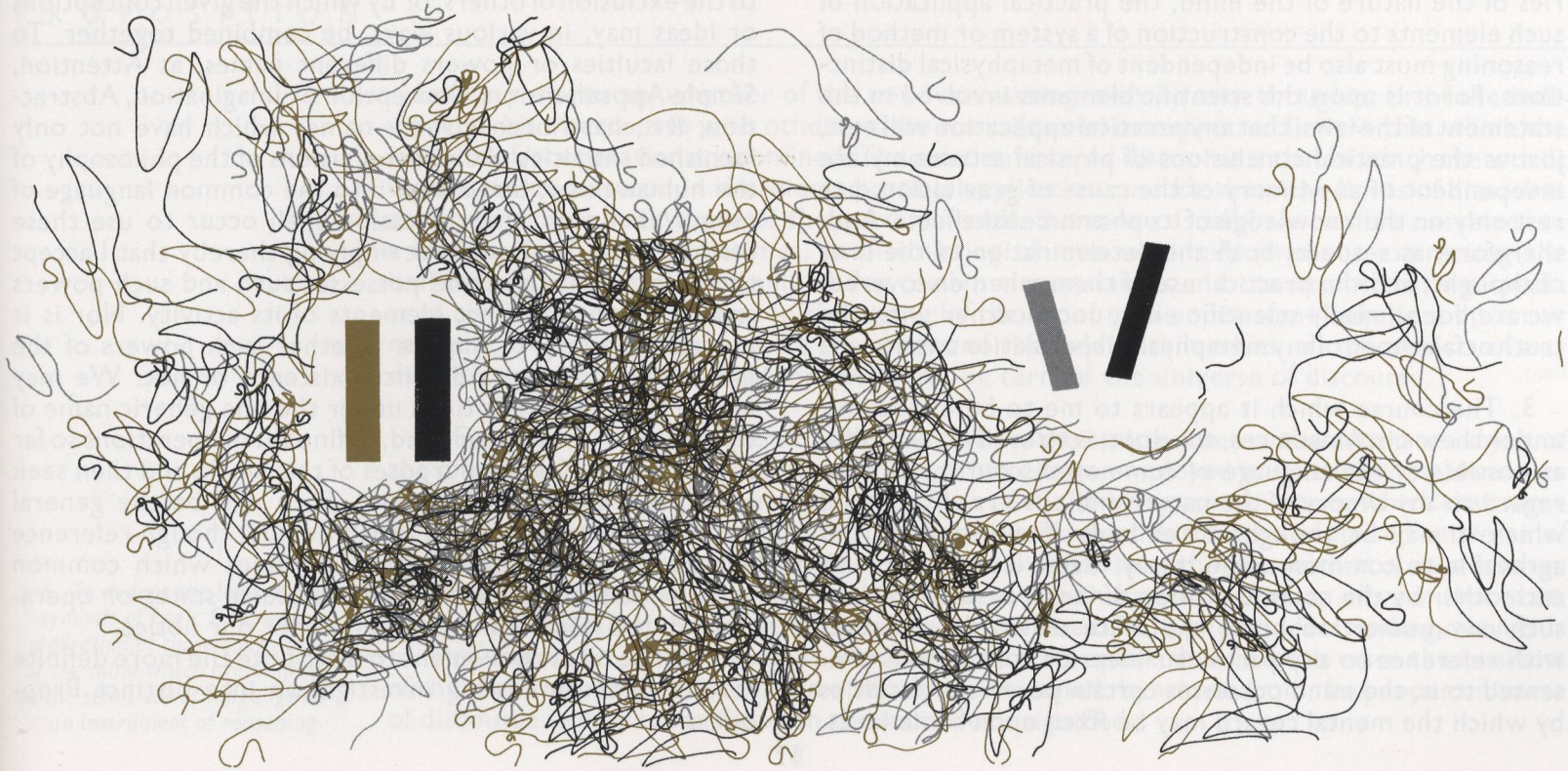
CHAPTER III

1. The object of science, properly so called, is the knowledge of laws and relations. To be able to distinguish what is essential to this end, from what is only accidentally associated with it, is one of the most important conditions of scientific progress. I say, to *distinguish* between these elements, because a consistent devotion to science does not require that the attention should be altogether withdrawn from other speculations, often of a metaphysical nature, with which it is not unfrequently connected. Such questions, for instance, as the existence of a sustaining ground of phænomena, the reality of cause, the propriety of forms of speech implying that the successive states of things are connected by *operations*, and others of a like nature, may possess a deep interest and significance in relation to science, without being essentially scientific. It is indeed scarcely possible to express the

conclusions of natural science without borrowing the language of these conceptions. Nor is there necessarily any practical inconvenience arising from this source. They who believe, and they who refuse to believe, that there is more in the relation of cause and effect than an invariable order of succession, agree in their interpretation of the conclusions of physical astronomy. But they only agree because they recognise a common element of scientific truth, which is independent of their particular views of the nature of causation.

2. If this distinction is important in physical science, much more does it deserve attention in connexion with the science of the intellectual powers. For the questions which this science presents become, in expression at least, almost necessarily mixed up with modes of thought and language, which betray a metaphysical origin. The idealist would give to the laws of reasoning one form of expression; the sceptic, if true to his principles, another. They who regard the phænomena with which we are concerned in this inquiry as the mere successive *states* of the thinking subject devoid of any causal connexion, and they who refer them to the *operations* of an active intelligence, would, if consistent, equally differ in their modes of statement. Like difference would also result from a difference of classification of the mental faculties. Now the principle which I would here assert, as affording us the only ground of confidence and stability amid so much of seeming and of real diversity, is the following, viz., that if the laws in question are really deduced from observation, they have a real existence as laws of the human mind, independently of any metaphysical theory which may seem to be involved in the mode of their statement. They contain an element of truth which no ulterior criticism upon the nature, or even upon the reality, of the mind's operations, can essentially affect. Let it even be granted that the mind is but a succession of states of consciousness, a series of fleeting impressions uncaused from without or from within, emerging out of nothing, and returning into nothing again,—the last refinement of the sceptic intellect,—still, as laws of succession, or at least of a past succession, the results to which observation had led would remain true. They would require to be interpreted into a language from whose vocabulary all such terms as cause and effect, operation and subject, substance and attribute, had been banished; but they would still be valid as scientific truths.

Moreover, as any statement of the laws of thought, founded upon actual observation, must thus contain scientific elements which are independent of metaphysical theo-



ries of the nature of the mind, the practical application of such elements to the construction of a system or method of reasoning must also be independent of metaphysical distinctions. For it is upon the scientific elements involved in the statement of the laws, that any practical application will rest, just as the practical conclusions of physical astronomy are independent of any theory of the cause of gravitation, but rest only on the knowledge of its phænomenal effects. And, therefore, as respects both the determination of the laws of thought, and the practical use of them when discovered, we are, for all really scientific ends, unconcerned with the truth or falsehood of any metaphysical speculations whatever.

3. The course which it appears to me to be expedient, under these circumstances, to adopt, is to avail myself as far as possible of the language of common discourse, without regard to any theory of the nature and powers of the mind which it may be thought to embody. For instance, it is agreeable to common usage to say that we converse with each other by the communication of ideas, or conceptions, such communication being the office of words; and that with reference to any particular ideas or conceptions presented to it, the mind possesses certain powers or faculties by which the mental regard may be fixed upon some ideas, to the exclusion of others, or by which the given conceptions or ideas may, in various ways, be combined together. To those faculties or powers different names, as Attention, Simple Apprehension, Conception or Imagination, Abstraction, &c., have been given,—names which have not only furnished the titles of distinct divisions of the philosophy of the human mind, but passed into the common language of men. Whenever, then, occasion shall occur to use these terms, I shall do so without implying thereby that I accept the theory that the mind possesses such and such powers and faculties as distinct elements of its activity. Nor is it indeed necessary to inquire whether such powers of the understanding have a distinct existence or not. We may merge these different titles under the one generic name of *Operations* of the human mind, define these operations so far as is necessary for the purposes of this work, and then seek to express their ultimate laws. Such will be the general order of the course which I shall pursue, though reference will occasionally be made to the names which common agreement has assigned to the particular states or operations of the mind which may fall under our notice.

It will be most convenient to distribute the more definite results of the following investigation into distinct Propositions.

In every discourse, whether of the mind conversing with its own thoughts, or of the individual in his intercourse with others, there is an assumed or expressed limit within which the subjects of its operation are confined. The most unfettered discourse is that in which the words we use are understood in the widest possible application, and for them the limits of discourse are co-extensive with those of the universe itself. But more usually we confine ourselves to a less spacious field. Sometimes, in discoursing of men we imply (without expressing the limitation) that it is of men only under certain circumstances and conditions that we speak, as of civilized men, or of men in the vigour of life, or of men under some other condition or relation. Now, whatever may be the extent of the field within which all the objects of our discourse are found, that field may properly be termed the universe of discourse.

5. Furthermore, this universe of discourse is in the strictest sense the ultimate *subject* of the discourse. The office of any name or descriptive term employed under the limitations supposed is not to raise in the mind the conception of all the beings or objects to which that name or description is applicable, but only of those which exist within the supposed universe of discourse. If that universe of discourse is the actual universe of things, which it always is when our words are taken in their real and literal sense, then by men we mean *all men that exist*; but if the universe of discourse is limited by any antecedent implied understanding, then it is of men under the limitations thus introduced that we speak. It is in both cases the business of the word *men* to direct a certain operation of the mind, by which, from the proper universe of discourse, we select or fix upon the individuals signified.

4. To deduce the laws of the symbols of Logic from a consideration of those operations of the mind which are implied in the strict use of language as an instrument of reasoning.

6. Exactly of the same kind is the mental operation implied by the use of an adjective. Let, for instance, the universe of discourse be the actual Universe. Then, as the word *men* directs us to select mentally from that Universe all the beings to which the term "men" is applicable; so the adjective "good," in the combination "good men," directs us still further to select mentally from the class of *men* all those who possess the further quality "good"; and if another adjective were prefixed to the combination "good men," it would direct a further operation of the same nature, having reference to that further quality which it might be chosen to express.

It is important to notice carefully the real nature of the operation here described, for it is conceivable, that it might have been different from what it is. Were the adjective simply *attributive* in its character, it would seem, that when a particular set of beings is designated by *men*, the prefixing of the adjective *good* would direct us to attach mentally to all those beings the quality of goodness. But this is not the real office of the adjective. The operation which we really perform is one of *selection according to a prescribed principle or idea*. To what faculties of mind such an operation would be referred, according to the received classification of its powers, it is not important to inquire, but I suppose that it would be considered as dependent upon the two faculties of Conception or Imagination, and Attention. To the one of these faculties might be referred the formation of the general conception; to the other the fixing of the mental regard upon those individuals within the prescribed universe of discourse which answer to the conception. If, however, as seems not improbable, the power of Attention is nothing more than the power of continuing the exercise of any other faculty of the mind, we might properly regard the whole of the mental process above described as referrible to the mental faculty of Imagination or Conception, the first step of the process being the conception of the Universe itself, and each succeeding step limiting in a definitive manner the conception thus formed. Adopting this view, I shall describe each such step, or any definite combination of such steps, as a *definitive act of conception*. And the use of this term I shall extend so as to include in its meaning not only the conception of classes of objects represented by particular names or simple attributes of quality, but also the combination of such conceptions in any manner consistent with the powers and limitations of the human mind; indeed, any intellectual operation short of that which is involved in the structure of a sentence or proposition. The general laws to which such operations of the mind are subject are now to be



considered.

7. Now it will be shown that the laws which in the preceding chapter have been determined *a posteriori* from the constitution of language, for the use of the literal symbols of Logic, are in reality the laws of that definite mental operation which has just been described. We commence our discourse with a certain understanding as to the limits of its subject, *i.e.* as to the limits of its Universe. Every name, every term of description that we employ, directs him whom we address to the performance of a certain mental operation upon that subject. And thus is thought communicated. But as each name or descriptive term is in this view but the representative of an intellectual operation, that operation being also prior in the order of nature, it is clear that the laws of the name or symbol must be of a derivative character,—must, in fact, originate in those of the operation which they represent. That the laws of the symbol and of the mental process are identical in expression will now be shown.

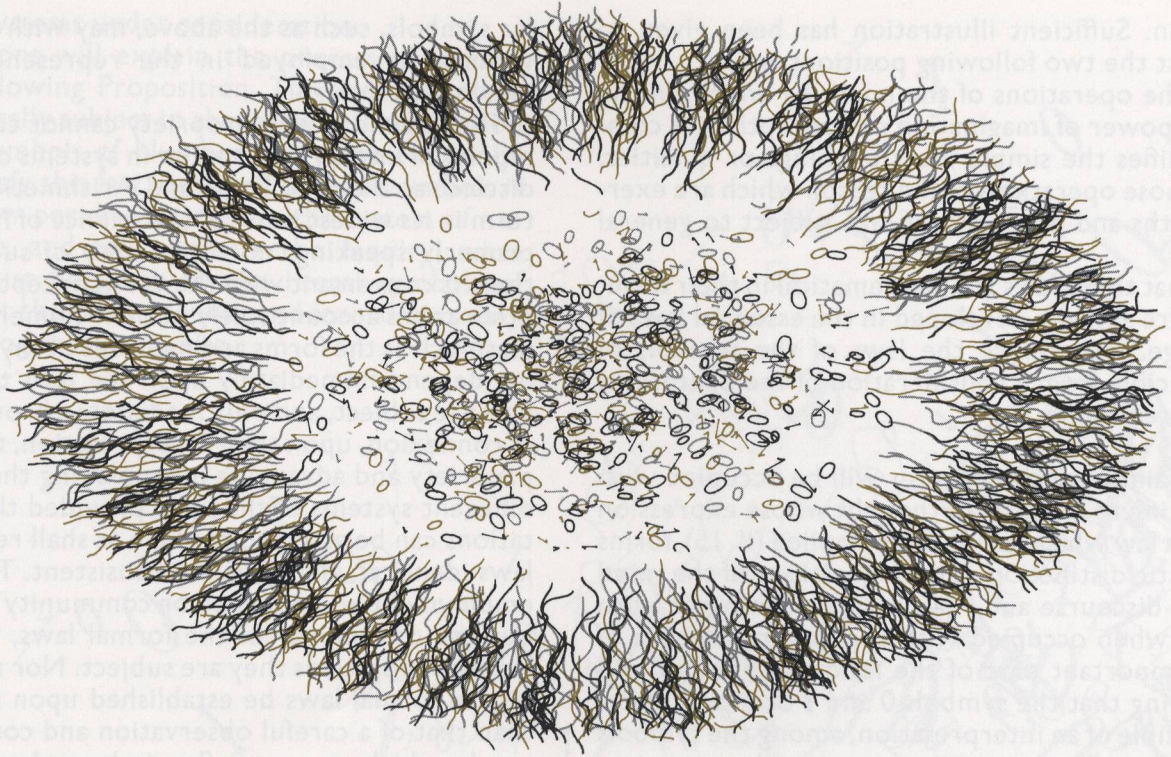
8. Let us then suppose that the universe of our discourse is the actual universe, so that words are to be used in the full extent of their meaning, and let us consider the two

mental operations implied by the words "white" and "men." The word "men" implies the operation of selecting in thought from its subject, the universe, all men; and the resulting conception, *men*, becomes the subject of the next operation. The operation implied by the word "white" is that of selecting from its subject, "men," all of that class which are white. The final conception is that of "white men." Now it is perfectly apparent that if the operations above described had been performed in a converse order, the result would have been the same. Whether we begin by forming the conception of "*men*," and then by a second intellectual act limit that conception to "white men," or whether we begin by forming the conception of "white objects," and then limit it to such of that class as are "men," is perfectly indifferent so far as the result is concerned. It is obvious that the order of the mental processes would be equally indifferent if for the words "white" and "men" we substituted any other descriptive or appellative terms whatever, provided only that their meaning was fixed and absolute. And thus the indifference of the order of two successive acts of the faculty of Conception, the one of which furnishes the subject upon which the other is supposed to operate, is a general condition of the exercise of that faculty. It is a law of the mind, and it is the real origin of that law of the literal symbols of Logic which constitutes its formal expression (i) Chap. II.

9. It is equally clear that the mental operation above described is of such a nature that its effect is not altered by repetition. Suppose that by a definite act of conception the attention has been fixed upon men, and that by another exercise of the same faculty we limit it to those of the race who are white. Then any further repetition of the latter mental act, by which the attention is limited to white objects, does not in any way modify the conception arrived at, viz., that of white men. This is also an example of a general law of the mind, and it has its formal expression in the law ((2) Chap. II.) of the literal symbols.

10. Again, it is manifest that from the conceptions of two distinct classes of things we can form the conception of that collection of things which the two classes taken together compose; and it is obviously indifferent in what order of position or of priority those classes are presented to the mental view. This is another general law of the mind, and its expression is found in (3) Chap. II.

11. It is not necessary to pursue this course of inquiry



and comparison. Sufficient illustration has been given to render manifest the two following positions, viz.:

First, That the operations of the mind, by which, in the exercise of its power of imagination or conception, it combines and modifies the simple ideas of things or qualities, not less than those operations of the reason which are exercised upon truths and propositions, are subject to general laws.

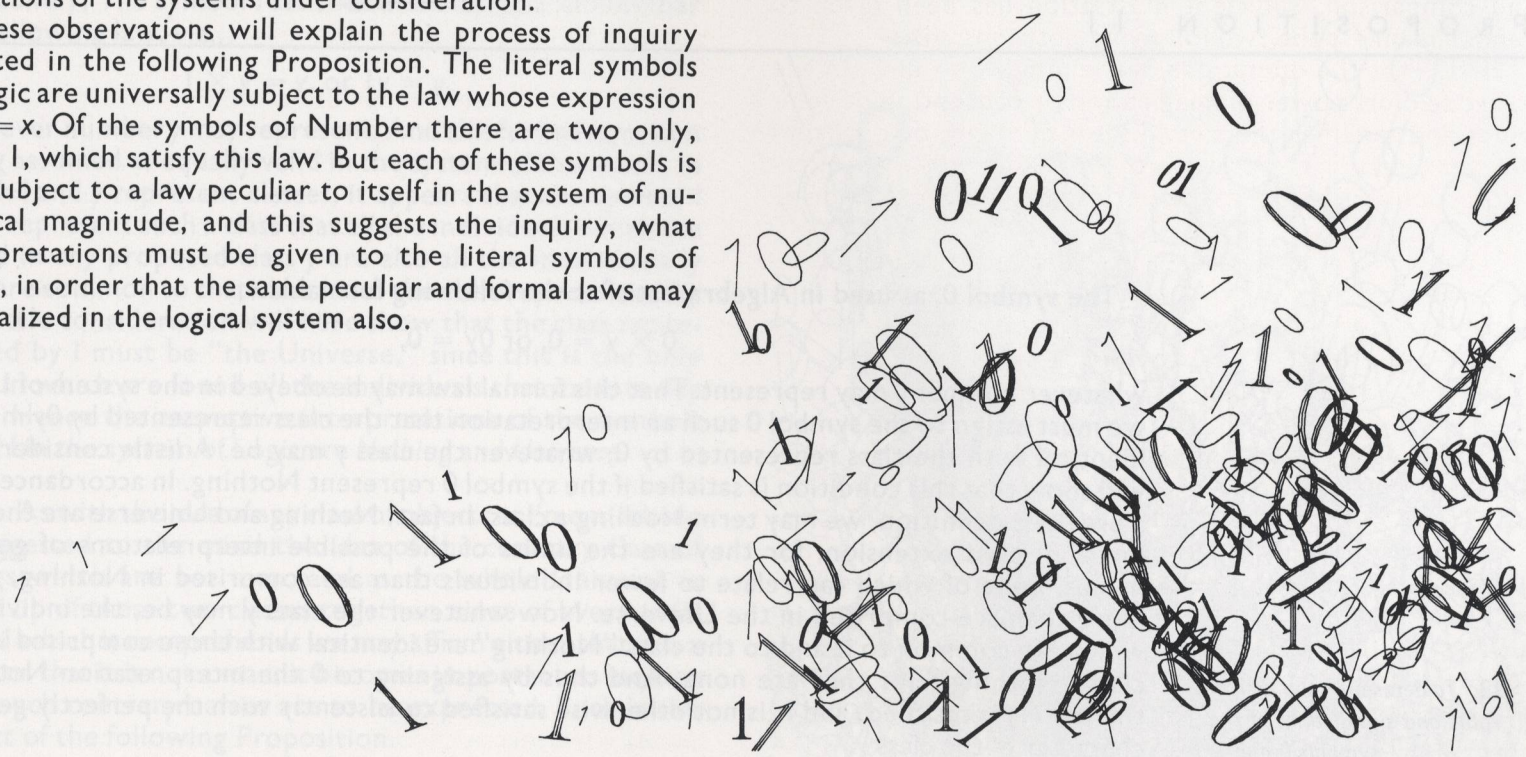
Secondly, That those laws are mathematical in their form, and that they are actually developed in the essential laws of human language. Wherefore the laws of the symbols of Logic are deducible from a consideration of the operations of the mind in reasoning.

12. The remainder of this chapter will be occupied with questions relating to that law of thought whose expression is $x^2 = x$ (II. 9), a law which, as has been implied (II. 15), forms the characteristic distinction of the operations of the mind in its ordinary discourse and reasoning, as compared with its operations when occupied with the general algebra of quantity. An important part of the following inquiry will consist in proving that the symbols 0 and 1 occupy a place, and are susceptible of an interpretation, among the symbols of Logic; and it may first be necessary to show how particular symbols, such as the above, may with propriety and advantage be employed in the representation of distinct systems of thought.

The ground of this propriety cannot consist in any community of interpretation. For in systems of thought so truly distinct as those of Logic and Arithmetic (I use the latter term in its widest sense as the science of Number), there is, properly speaking, no community of subject. The one of them is conversant with the very conceptions of things, the other takes account solely of their numerical relations. But inasmuch as the forms and methods of any system of reasoning depend immediately upon the laws to which the symbols are subject, and only mediately, through the above link of connexion, upon their interpretation, there may be both propriety and advantage in employing the same symbols in different systems of thought, provided that such interpretations can be assigned to them as shall render their formal laws identical, and their use consistent. The ground of that employment will not then be community of interpretation, but the community of the formal laws, to which in their respective systems they are subject. Nor must that community of formal laws be established upon any other ground than that of a careful observation and comparison of those results which are seen to flow independently from the inter-

pretations of the systems under consideration.

These observations will explain the process of inquiry adopted in the following Proposition. The literal symbols of Logic are universally subject to the law whose expression is $x^2 = x$. Of the symbols of Number there are two only, 0 and 1, which satisfy this law. But each of these symbols is also subject to a law peculiar to itself in the system of numerical magnitude, and this suggests the inquiry, what interpretations must be given to the literal symbols of Logic, in order that the same peculiar and formal laws may be realized in the logical system also.



PROPOSITION II

13. *To determine the logical value and significance of the symbols* 0 *and* 1.

The symbol 0, as used in Algebra, satisfies the following formal law,

$$0 \times y = 0, \text{ or } 0y = 0, \tag{1}$$

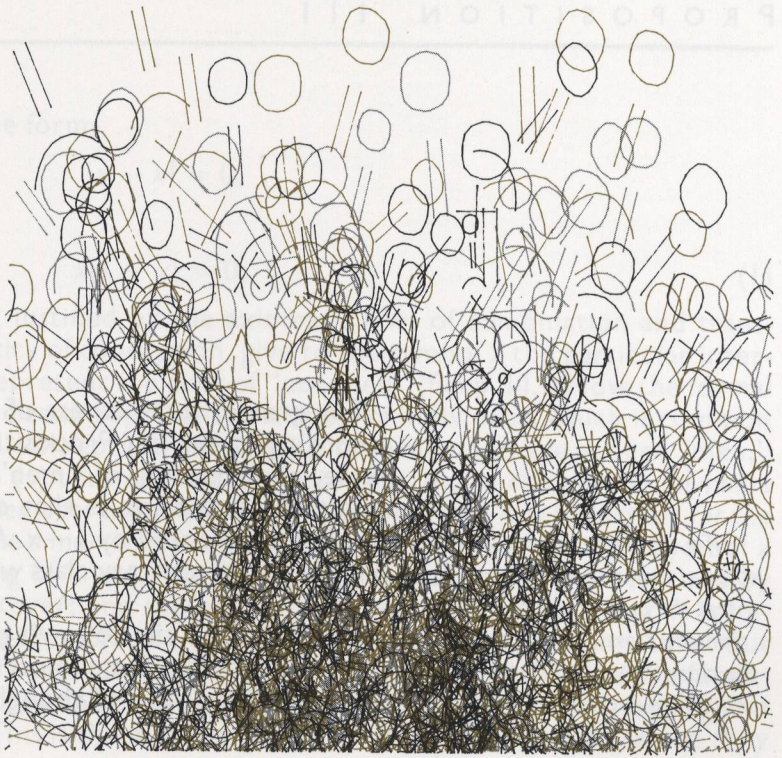
whatever number y may represent. That this formal law may be obeyed in the system of Logic, we must assign to the symbol 0 such an interpretation that the *class* represented by $0y$ may be identical with the class represented by 0, whatever the class y may be. A little consideration will show that this condition is satisfied if the symbol 0 represent Nothing. In accordance with a previous definition, we may term Nothing a class. In fact, Nothing and Universe are the two limits of class extension, for they are the limits of the possible interpretations of general names, none of which can relate to fewer individuals than are comprised in Nothing, or to more than are comprised in the Universe. Now whatever the class y may be, the individuals which are common to it and to the class "Nothing" are identical with those comprised in the class "Nothing," for they are none. And thus by assigning to 0 the interpretation Nothing, the law (1) is satisfied; and it is not otherwise satisfied consistently with the perfectly general character of the class y.

Secondly, The symbol 1 satisfies in the system of Number the following law, viz.,

$$1 \times y = y, \text{ or } 1y = y,$$

whatever number y may represent. And this formal equation being assumed as equally valid in the system of this work, in which 1 and y represent classes, it appears that the symbol 1 must represent such a class that all the individuals which are found in *any* proposed class y are also all the individuals $1y$ that are common to that class y and the class represented by 1. A little consideration will here show that the class represented by 1 must be "the Universe," since this is the only class in which are found *all* the individuals that exist in *any* class. Hence the respective interpretations of the symbols 0 and 1 in the system of Logic are *Nothing* and *Universe*.

14. As with the idea of any class of objects as "men," there is suggested to the mind the idea of the contrary class of beings which are not men; and as the whole Universe is made up of these two classes together, since of every individual which it comprehends we may affirm either that it is a man, or that it is not a man, it becomes important to inquire how such contrary names are to be expressed. Such is the object of the following Proposition.



PROPOSITION III

If x represent any class of objects, then will 1 − x represent the contrary or supplementary class of objects, i.e. the class including all objects which are not comprehended in the class x.

For greater distinctness of conception let x represent the class *men*, and let us express, according to the last Proposition, the Universe by 1; now if from the conception of the Universe, as consisting of "men" and "not-men," we exclude the conception of "men," the resulting conception is that of the contrary class, "not-men." Hence the class "not-men" will be represented by $1 - x$. And, in general, whatever class of objects is represented by the symbol x, the contrary class will be expressed by $1 - x$.

15. Although the following Proposition belongs in strictness to a future chapter of this work, devoted to the subject of *maxims* or *necessary truths*, yet, on account of the great importance of that law of thought to which it relates, it has been thought proper to introduce it here.

Let us write this equation in the form

$$x - x^2 = 0,$$

whence we have

$$x(1 - x) = 0; \qquad (1)$$

both these transformations being justified by the axiomatic laws of combination and transposition (II. 13). Let us, for simplicity of conception, give to the symbol x the particular interpretation of *men*, then $1 - x$ will represent the class of "not-men" (Prop. III.). Now the formal product of the expressions of two classes represents that class of individuals which is common to them both (II. 6). Hence $x(1 - x)$ will represent the class whose members are at once "men," and "not men," and the equation (1) thus express the principle, *that a class whose members are at the same time men and not men does not exist.* In other words, that *it is impossible for the same individual to be at the same time a man and not a man.* Now let the meaning of the symbol x be extended from the representing of "men," to that of any class of beings characterized by the possession of any quality whatever; and the equation (1) will then express that it is impossible for a being to possess a quality and not to possess that quality at the same time. But this is identically that "principle of contradiction" which Aristotle has described as the fundamental axiom of all philosophy. "It is impossible that the same quality should both belong and not belong to the same thing. . . . This is the most certain of all principles. . . . Wherefore they

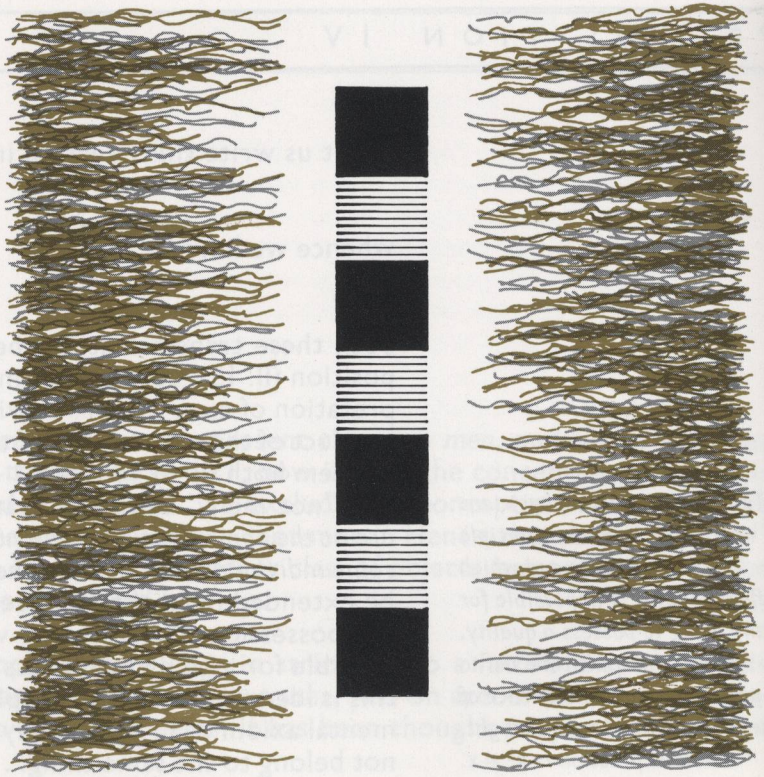
That axiom of metaphysicians which is termed the principle of contradiction, and which affirms that it is impossible for any being to possess a quality, and at the same time not to possess it, is a consequence of the fundamental law of thought, whose expression is $x^2 = x$.

who demonstrate refer to this as an ultimate opinion. For it is by nature the source of all the other axioms." *

The above interpretation has been introduced not on account of its immediate value in the present system, but as an illustration of a significant fact in the philosophy of the intellectual powers, viz., that what has been commonly regarded as the fundamental axiom of metaphysics is but the consequence of a law of thought, mathematical in its form. I desire to direct attention also to the circumstance that the equation (1) in which that fundamental law of thought is expressed is an equation of the second degree. **

*Τὸ γὰρ αὐτό ἅμα ὑπάρχειν τε καὶ μὴ ὑπάρχειν ἀδύνατον τῷ αὐτῷ καὶ κατὰ τὸ αὐτό. . . Αὐτὴ δὴ πασῶν ἐστὶ βεβαιοτάτη τῶυ ἀρχῶν. . . Διὸ πάντες οἱ ἀποδεικνύντες εἰς ταύτην ἀνάγουσιν ἐσχάτην δόξαν· φύσει γὰρ ἀρχὴ καὶ τῶν ἄλλων ἀξιωμάτων αὐτή πάντων.—*Metaphysica*, III. 3.

**Should it here be said that the existence of the equation $x^2 = x$ necessitates also the existence of the equation $x^3 = x$, which is of the third degree, and then inquired whether that equation does not indicate a process of *trichotomy*; the answer is,



Without speculating at all in this chapter upon the question, whether that circumstance is necessary in its own nature, we may venture to assert that if it had not existed, the whole procedure of the understanding would have been different from what it is. Thus it is a consequence of the fact that the fundamental equation of thought is of the second degree, that we perform the operation of analysis and classification, by division into pairs of opposites, or, as it is technically said, by *dichotomy*. Now if the equation in question had been of the third degree, still admitting of interpretation as such, the mental division must have been threefold in character, and we must have proceeded by a species of *trichotomy*, the real nature of which it is impossible for us, with our existing faculties, adequately to conceive, but the laws of which we might still investigate as an object of intellectual speculation.

16. The law of thought expressed by the equation (1) will, for reasons which are made apparent by the above discussion, be occasionally referred to as the "law of duality."

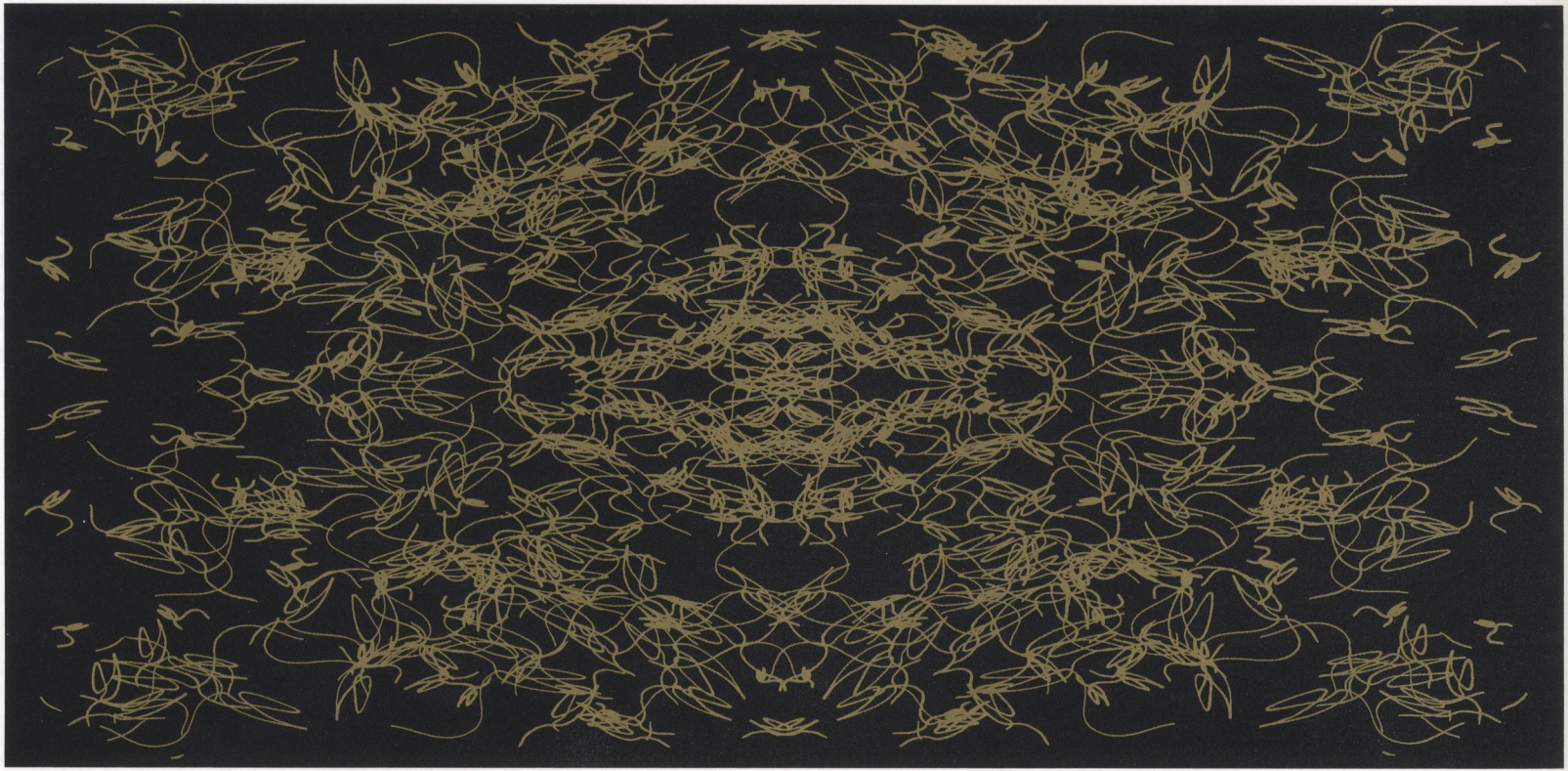
that the equation $x^3 = x$ is not interpretable in the system of logic. For writing it in either of the forms

$$x(1 - x)(1 + x) = 0, \quad (2)$$

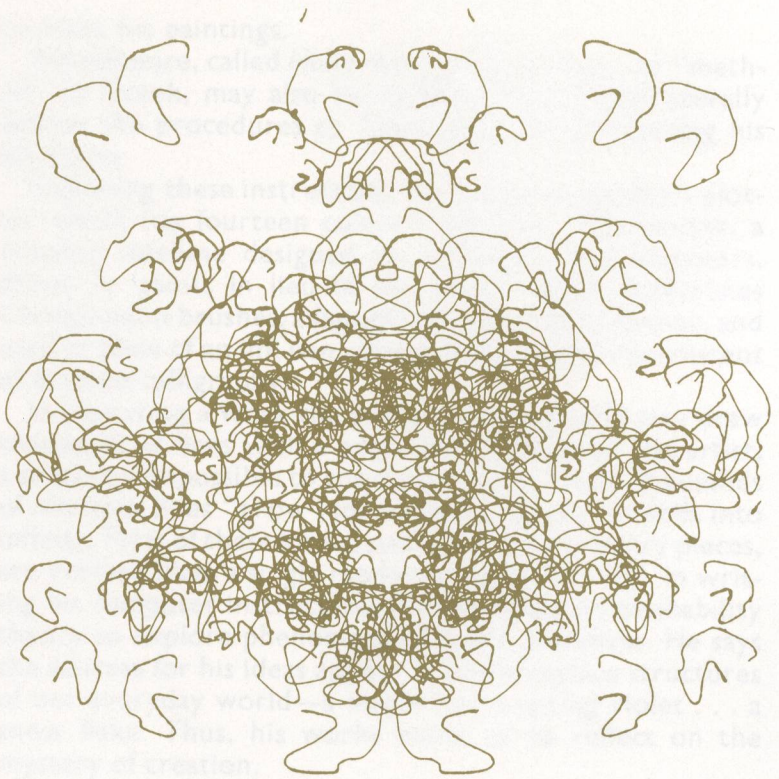
$$x(1 - x)(-1 - x) = 0, \quad (3)$$

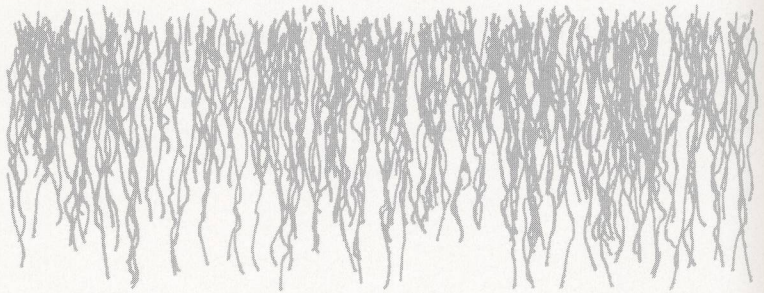
we see that its interpretation, if possible at, all must involve that of the factor $1 + x$, or of the factor $-1 - x$. The former is not interpretable, because we cannot conceive of the addition of any class x to the universe 1; the latter is not interpretable, because the symbol -1 is not subject to the law $x(1 - x) = 0$, to which all class symbols are subject. Hence the equation $x^3 = x$ admits of no interpretation analogous to that of the equation $x^2 = x$. Were the former equation, however, true independently of the latter, *i.e.* were that act of the mind which is denoted by the symbol x, such that its second repetition should reproduce the result of a single operation, but not its first or mere repetition, it is presumable that we should be able to interpret one of the forms (2), (3), which under the actual conditions of thought we cannot do. There exist operations, known to the mathematician, the law of which may be adequately expressed by the equation $x^3 = x$. But they are of a nature altogether foreign to the province of general reasoning.

In saying that it is conceivable that the law of thought might have been different from what it is, I mean only that we can frame such an hypothesis, and study its consequences. The possibility of doing this involves no such doctrine as that the actual law of human reason is the product either of chance or of arbitrary will.









Postscript

George Boole (1815–1864)—English mathematician—was one of the greatest logicians of the 19th century, and one of the most influential thinkers of all time. He is considered the discoverer of modern symbolic logic. His work has had interpretation in many fields, and is basic to switching theory and computer design. Boolean logic is fundamental to the structure of circuit boards and computer programs.

George Boole's father was a tradesman of limited means, but of studious character and active mind. He was his son's

first teacher, but for the most part Boole was self-taught. From the age of sixteen Boole was an educator. A genius of great modesty, he neither sought nor received the ordinary rewards to which his discoveries entitled him, although he did receive a medal from the Royal Society and an honorary degree from the University of Dublin. His interests were broad, extending widely into the humanities.

In our own time Boole is known in limited academic circles, but all of us benefit from his contributions seminal to the development of the computer. Roman Verostko's experiments with art and the computer led him to study and appreciate George Boole. Thus, when he collaborated with Saint Sebastian Press for its first edition, the choice of Boole's "Derivation of the Laws" from his *The Laws of Thought* seemed ideal—an opportunity to integrate computer art with an important work, and a tribute to the thinker who helped make it possible.

Roman Verostko's first use of computer technology dates back over twenty years. Within the past decade he has converted his Pathway Studio entirely to the new technology and has developed his own software to produce works of art. Much as a composer creates a score for a musical work to be performed by an orchestra, he creates works of art by writing instructions (software) for his computer about how to make his paintings.

His software, called *Hodos* which means "way" or "method" in Greek, may also be viewed as art. *Hodos* literally defines the procedures or "pathways" for structuring his art forms.

Following these instructions the computer guides a plotter which has fourteen colored ink pens. The plotter, a drawing machine designed for architects and engineers, draws or paints in lieu of the artist's hand. Sometimes Chinese paint brushes, adapted to the plotter by Roman, and used in place of an ink pen, create bold strokes reminiscent of oriental calligraphy.

In executing a work the plotter automatically may draw thousands of lines with a precision specified by the artist, a precision impossible to the human hand. These thousands of intricate lines "grow" forms which appear to drift into infinity. Most of these forms, such as in the symmetry pieces, are evolved from a single randomly generated line. In writing his computer instructions Roman draws on probability theory to explore phenomena of order and chaos. He says the sources for his ideas appear in commonplace structures of our everyday world—a maple leaf, a spring violet . . . a snow flake. Thus, his works invite us to reflect on the mystery of creation.

All the illustrations in this book were created by *HODOS*, an original computer software program written by Roman Verostko. The artwork was executed at Pathway Studio, Minneapolis, with a Houston Instruments DMP52, 14 Pen, Plotter coupled to a personal computer operating with MS DOS using *HODOS*. Chinese paint brushes were mounted on the plotter to execute the brush strokes.

The Pathway Studio seal, *Xiǎo Jìng Zhāi*, "Little Footpath Studio," was designed and carved by Wang Dong-Ling, Zhejiang Academy of Fine Arts, Hangzhou, People's Republic of China.

This first edition includes 5 artiste livre, 20 deluxe leather and 100 regular bindings, by Michael Norman.

The type, Gill Sans, cast by M&H Type of San Francisco, is printed on Frankfurt text, with Kohl & Madden inks, by Michael Tomaszewski.

The reproduction proofs for this paper bound edition were taken from the composition-set monotype used in the hand-pulled letterpress edition. All the text and printed illustrations are included from that first edition. Special front and end pieces created for this paperback appear in the place of the original "one of a kind" computer drawings which were tipped into the 125 subscription copies.

Computer generated illustrations by Roman Verostko illuminate *Derivation of the Laws*, a chapter reprinted from George Boole's *The Laws of Thought* (1854). In his preface Roger Malina, Executive Editor of *Leonardo*, discusses the fascinating relationships he sees emerging between art, science, and technology. He describes Verostko in "unholy conspiracy with Boole's progeny." "Like the naturalists who . . . bring the chimpanzee or dolphin into their homes and communicate through sign language or whistles, Verostko teaches this child (his PC) to paint."

The first ever plotter-brush paintings were created with Verostko's original software. He illustrated this book using that software as a tribute to the 19th century mathematician, George Boole. Boole's treatise demonstrates the direct link between Aristotle's principle of contradiction and the symbolic logic known today as Boolean algebra, a symbolic language seminal to modern computer technology. The illustrations, generated by Verostko's algorithms which operate on the principles outlined in Boole's *Laws*, exemplify the profound kinship emerging today between art and science.

Verostko, artist and professor of world art history at the Minneapolis College of Art and Design, explores and improvises visual forms which were not accessible before the computer. His paper on *Epigenetic Painting* at the First International Congress on Electronic Art (Utrecht, 1988; *Leonardo 23:1*) outlined features of his software which he believes will be used commonly by artists in the next generation.

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